ITER and beyond

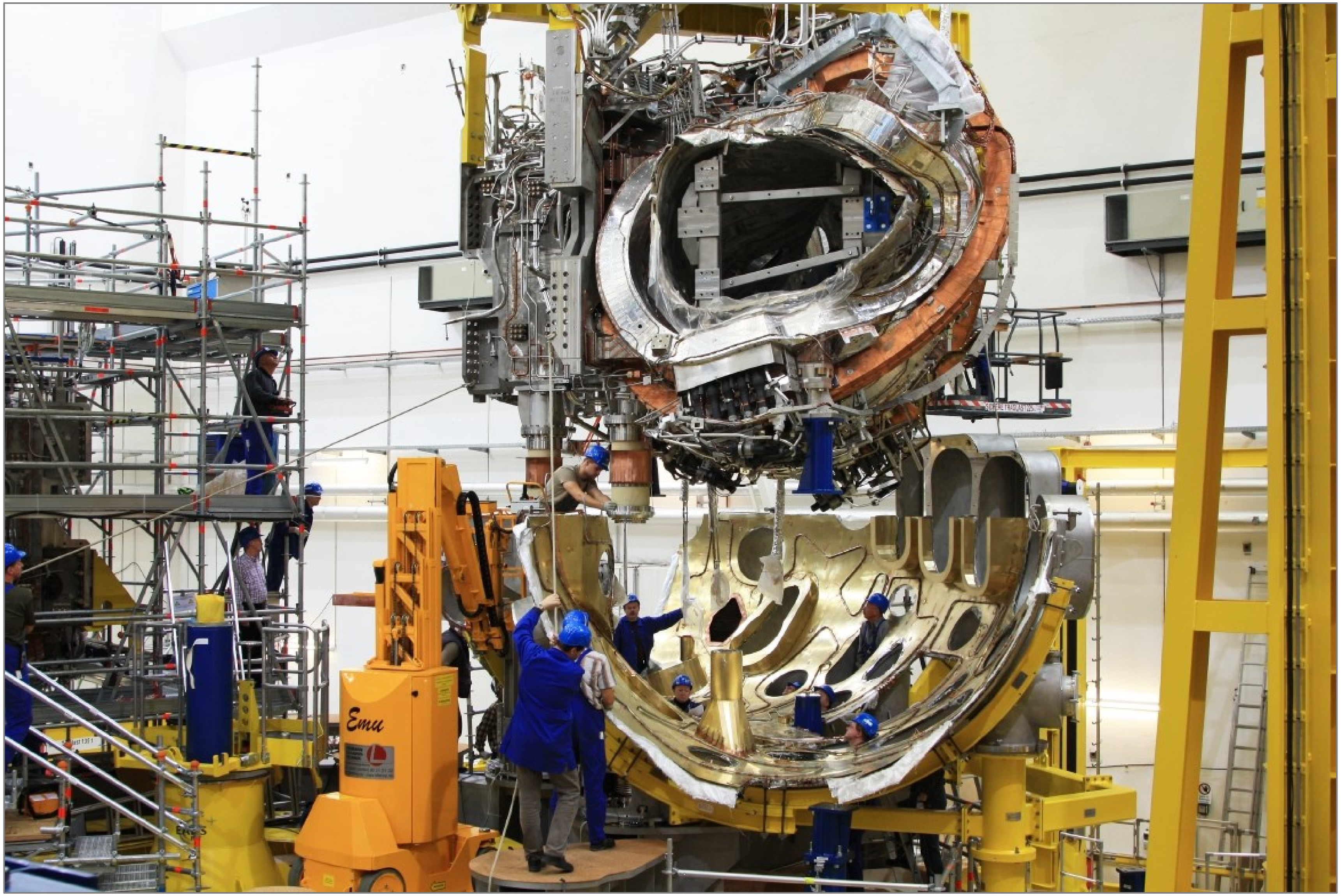
MEPhI, Moscow, 9October 2017
Guido Van Oost, Ghent University, Belgium & MEPhI,Russia

Current status in fusion research

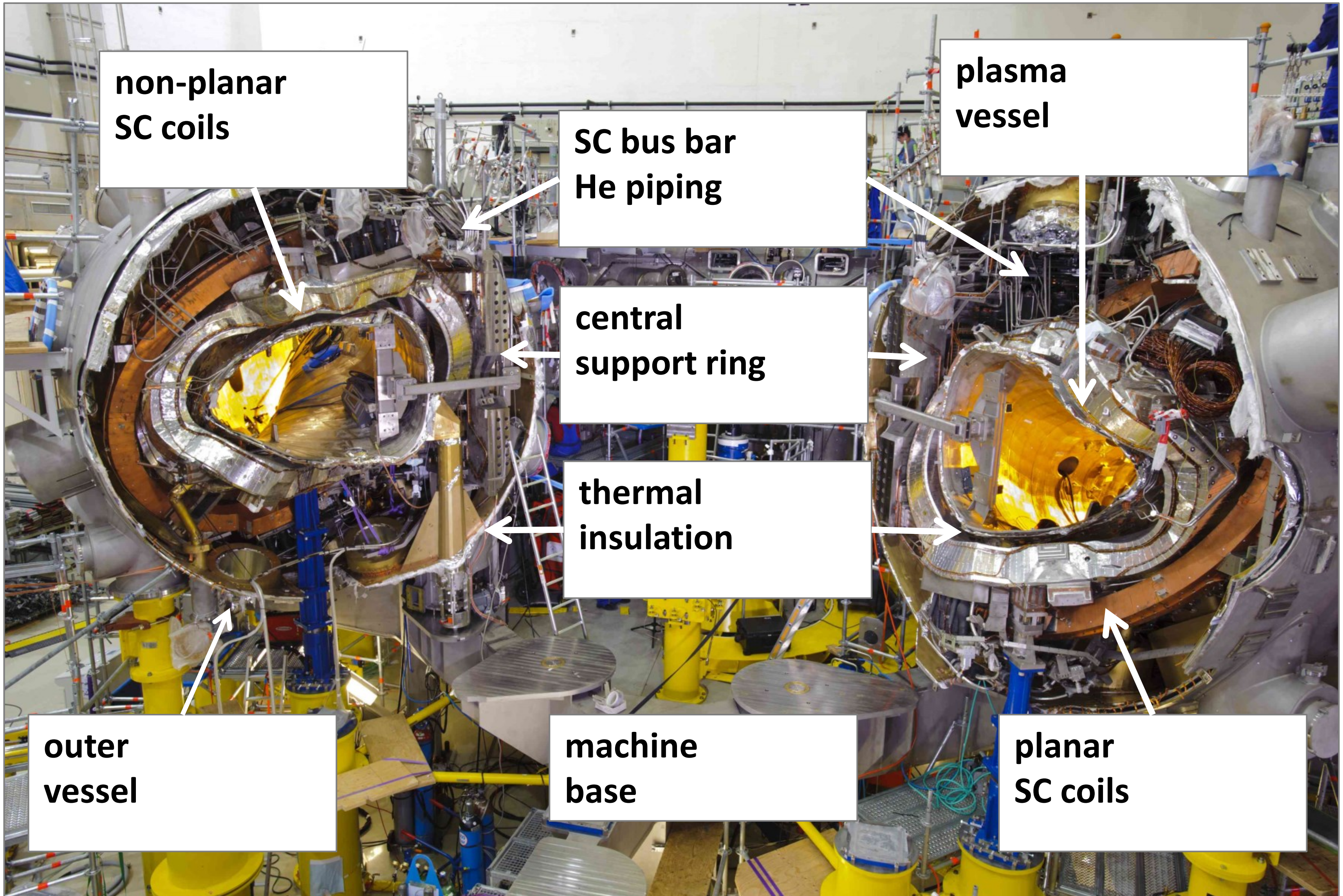
Relatively good situation in Asia and EU

- **Fully superconducting tokamaks in Asia:**
  EAST, K-STAR, (SST-1)
- **In Europe, several upgrades:**
  WEST, MAST, TCV…COMPASS Upgrade ??
- Wendelstein 7-X
- New phenomena in EU: fusion education, also a new level of industrial involvement (fusion engineering) +link

W7-X Integration of the magnet module



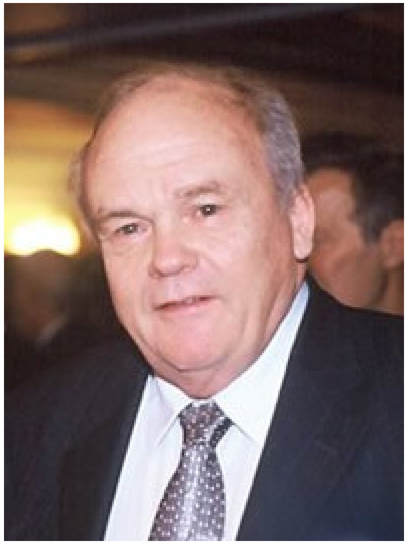
W7-X Four out of five modules



History of fusion reactor

INTOR: "INternational TOkamak Reactor"

- Conferences since 1958, IAEA sponsored
- In Europe, EURATOM launches joint fusion research in 1970
- Academician RAS **Yevgeny Velikhov** in 1978 proposes that the IAEA form a specialist group to assess feasibility of a reactor + conceptual study (4 parties), no commitments
- → INTOR workshops, ~ 150 experts in each partner country
- 1979: Yes the machine is feasible, go to Phase 1
- 1981: conceptual design complete. Primitive reactor, call for increased R&D funding. No support to continue.
- 1985: Pres.M.Gorbachov proposes to Pres. F.Mitterrand and later to Pres. R.Reagan to commit to a fusion reactor



ITER pre-history

"The two leaders emphasized the potential importance of the work aimed at utilizing controlled thermonuclear fusion **for peaceful purposes** and, in this connection, advocated the widest practicable development of international cooperation in obtaining this source of energy, which is essentially inexhaustible, for the benefit of all mankind."

Joint Soviet-United States Statement at the Summit Meeting (Reagan – Gorbachov) in Geneva, November 21, 1985.

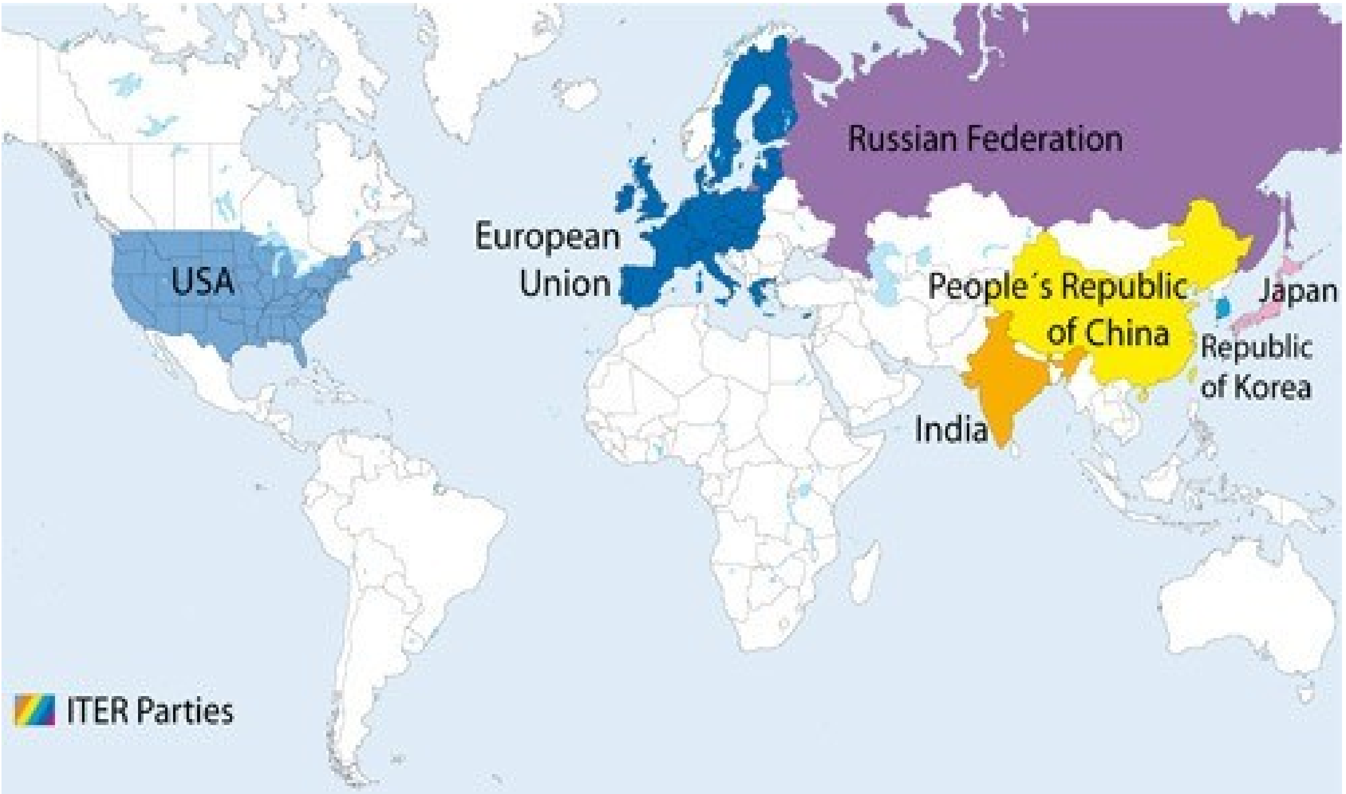
Similar declaration two months earlier in Gorbachov-Mitterrand meeting. In December 1985, UN General Assembly accepted.

New: commitment to build

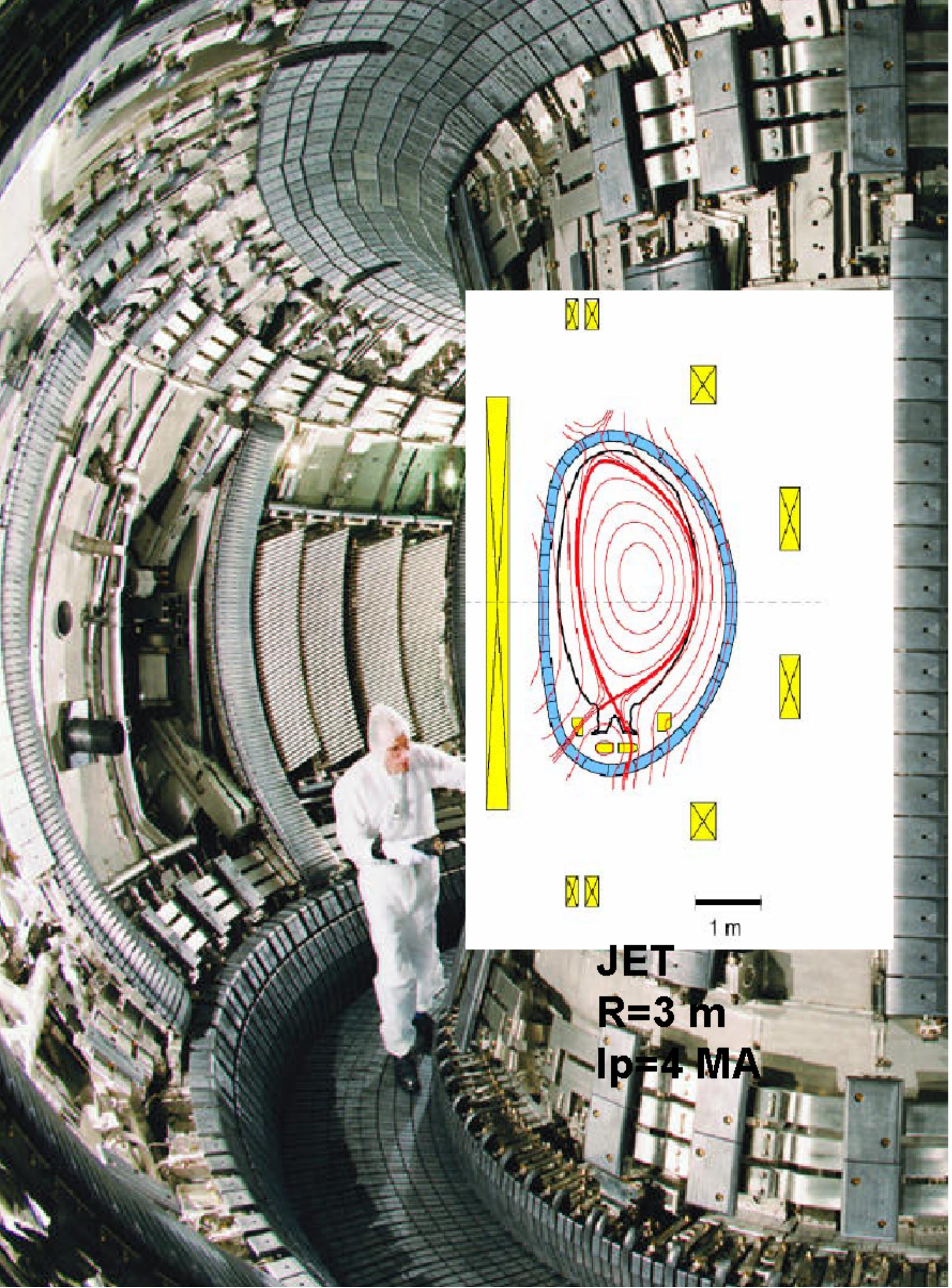
ITER history

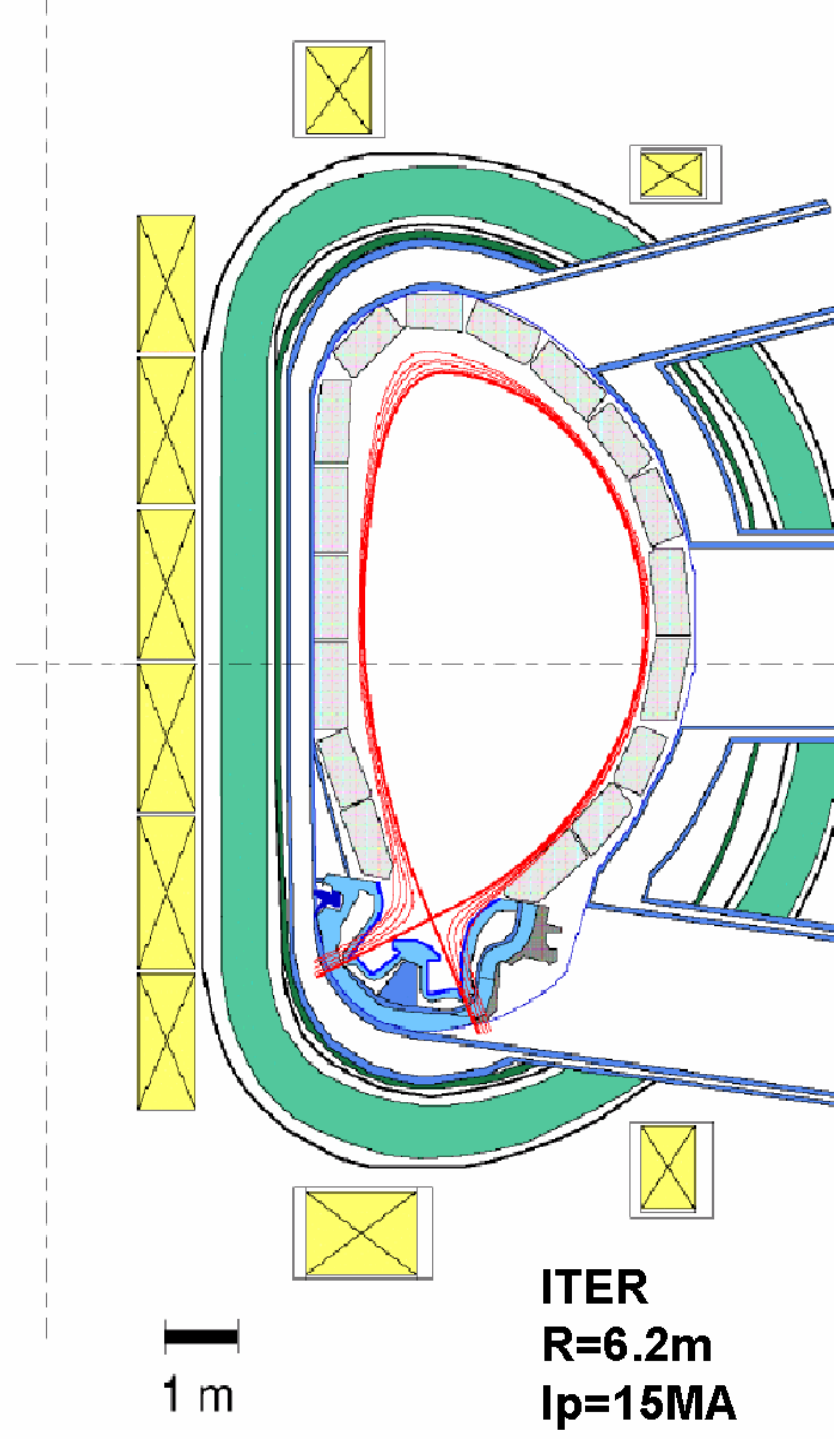
- 1987 ITER Agreement (USSR, USA, Europe, Japan)
- ITER CDA (Conceptual Design Activities)
- 1992 July 21st ITER EDA (Engineering Design Activities). Three Joint Design Teams in Naka, San Diego and Garching, ~170 experts
- 7 large R&D projects
- 1998 Final Design Report (large ITER, designed for ignition)
- USA withdraws, Russia weak… cost reduction, smaller "ITER FEAT" design done in 2001 → CTA (coordinated technical activities phase)
- ITER sites: Canada, Spain (Vandelos), Japan (Rokkasho-Mura), Cadarache (France)
- 2003 China and South Korea join, USA rejoins, 2005 India joins
- ITA (Interim Transitional Agreements) until the Construction phase → hand over from IAEA to ITER IO
- June 28, 2005 ITER sited in Cadarache (FUSION-EP starts in 2006)
- ITER agreement signed on 21st November 2006 in Paris, ratified by the last country on 24 October 2007 (date of birth of the ITER IO)
- "Broader approach" (EU – Japan) signed February 2007

- Because of its size and cost and the involvement of practically all the most developed countries, representing more than half of today world's population, ITER may become a new reference point for global science projects.
- The ITER project is one of the world's biggest scientific collaborations.



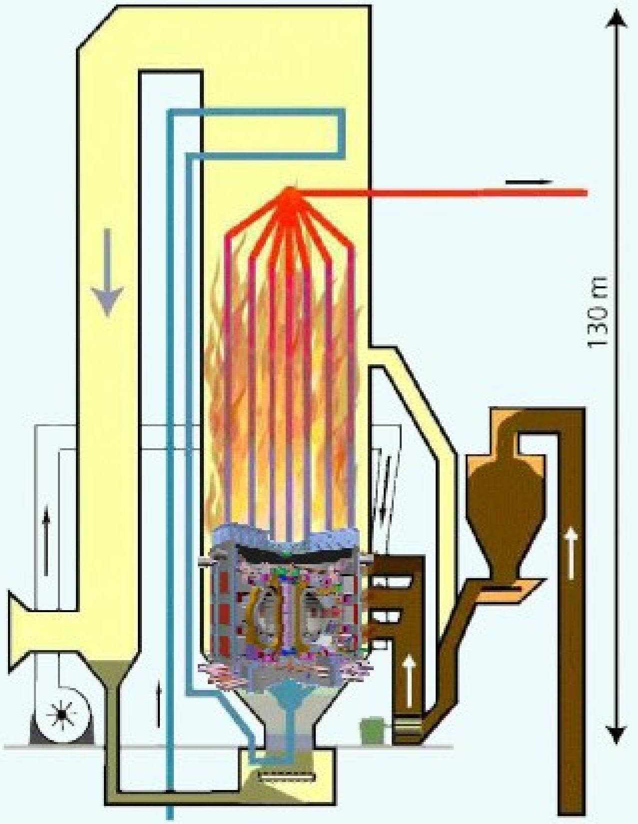
1. ITER


1 m
JET
R=3 m
Ip=4 MA


1 m
ITER
R=6.2m
Ip=15MA

ITER

compared to coal burner



ITER Goals

Power amplification factor $$Q = \frac{P_f}{P_H}$$

instead of the ignition, $Q \to \infty$ present ITER aims "only" at $Q \geq 10$

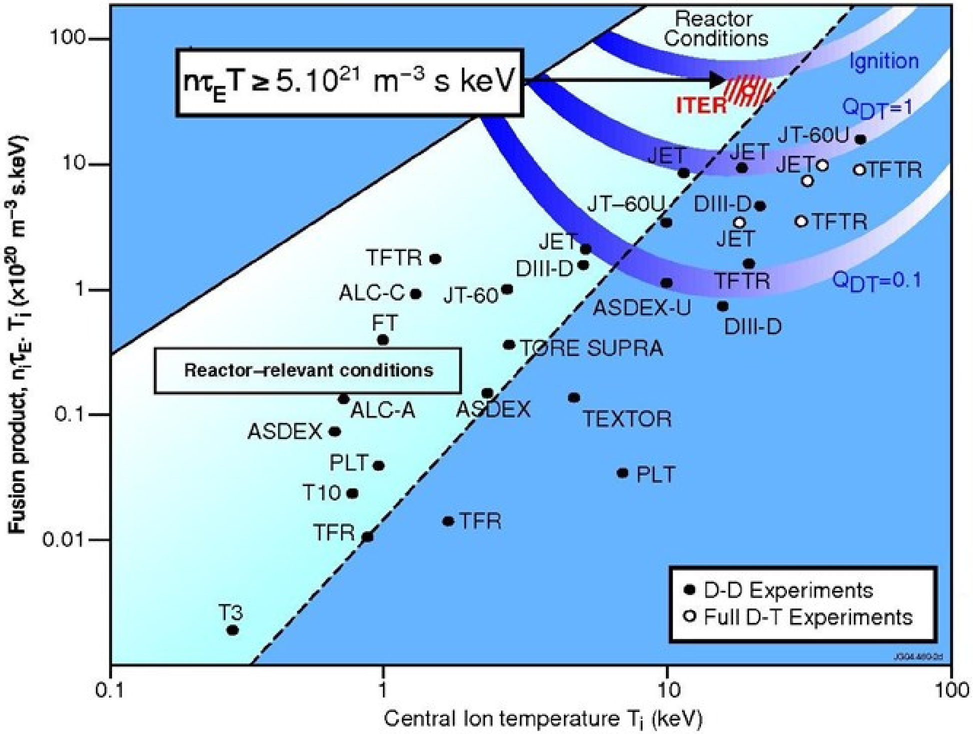
physics to be validated:
confinement scaling
stability
self-heating by alpha particles
exhaust of power and alpha particles

- with duration sufficient to achieve stationary conditions
- ignition is not precluded
- demonstrate non-inductive CD with $Q = 5$

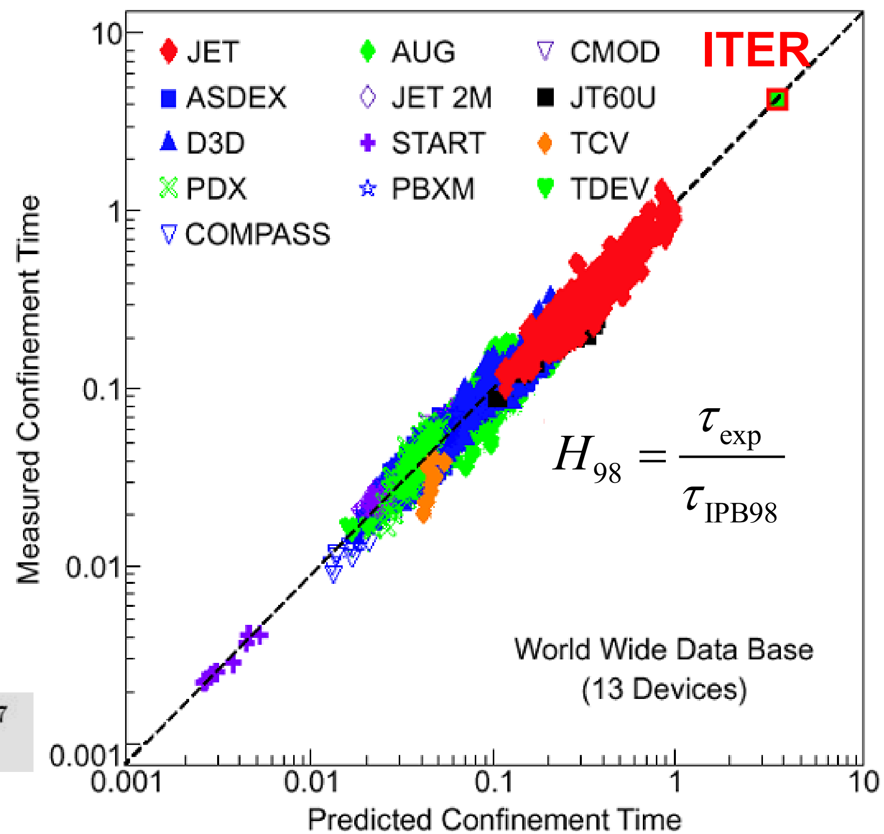
physics to be validated: self-sustainment of plasma current

- demonstrate technologies (SC, RH...)
- test reactor components
- develop tritium breeding (different TBMs – Test Breeding Modules)

Current status with respect to the ITER Goals



$$\tau_{E,IPB98(y)} = 0.0365\ I_p^{0.97}\ B_t^{0.08}\ P_{heat}^{-0.63}\ n_e^{0.41}\ M^{0.2}\ R^{1.93}\ \epsilon^{0.23}\ \kappa^{0.67}$$



$$H_{98} = \frac{\tau_{exp}}{\tau_{IPB98}}$$

ITER IO

Established on 24 October 2007 in Cadarache, France

1st director Kaname Ikeda, deputy Norbert Holtkamp
2nd director Osamu Motojima
3rd director (current) Bernard Bigot

ITER Council
4 representatives per member
Decides about senior staff, budget, and participation
Chairman Won Namkung, Rep. of Korea
(previous Robert Iotti, Hideyuki Takatsu,
Jevgenij Velikhov , Sir Chris Llewellyn Smith)

Advisory bodies of the Council:
+ STAC (Science and Technology Advisory Committee)
+ Management Advisory Committee

ITER Domestic Agencies

The Domestic Agencies' role is to handle the procurement of each Member's in-kind contributions to ITER. The Domestic Agencies employ their own staff and have their own budget, and place contracts with suppliers. They are responsible for organising and carrying out the procurement for each ITER Member.

The strongest (~50%) – EU: F4E in Barcelona, director Johannes Schwemmer
http://fusionforenergy.europa.eu/

governing board (Chair Joaquín Sanchez) + exec committee

paid by EURATOM

http://ec.europa.eu/research/energy/euratom/index_en.cfm

Agence ITER France http://www.itercad.org/

China www.iterchina.cn

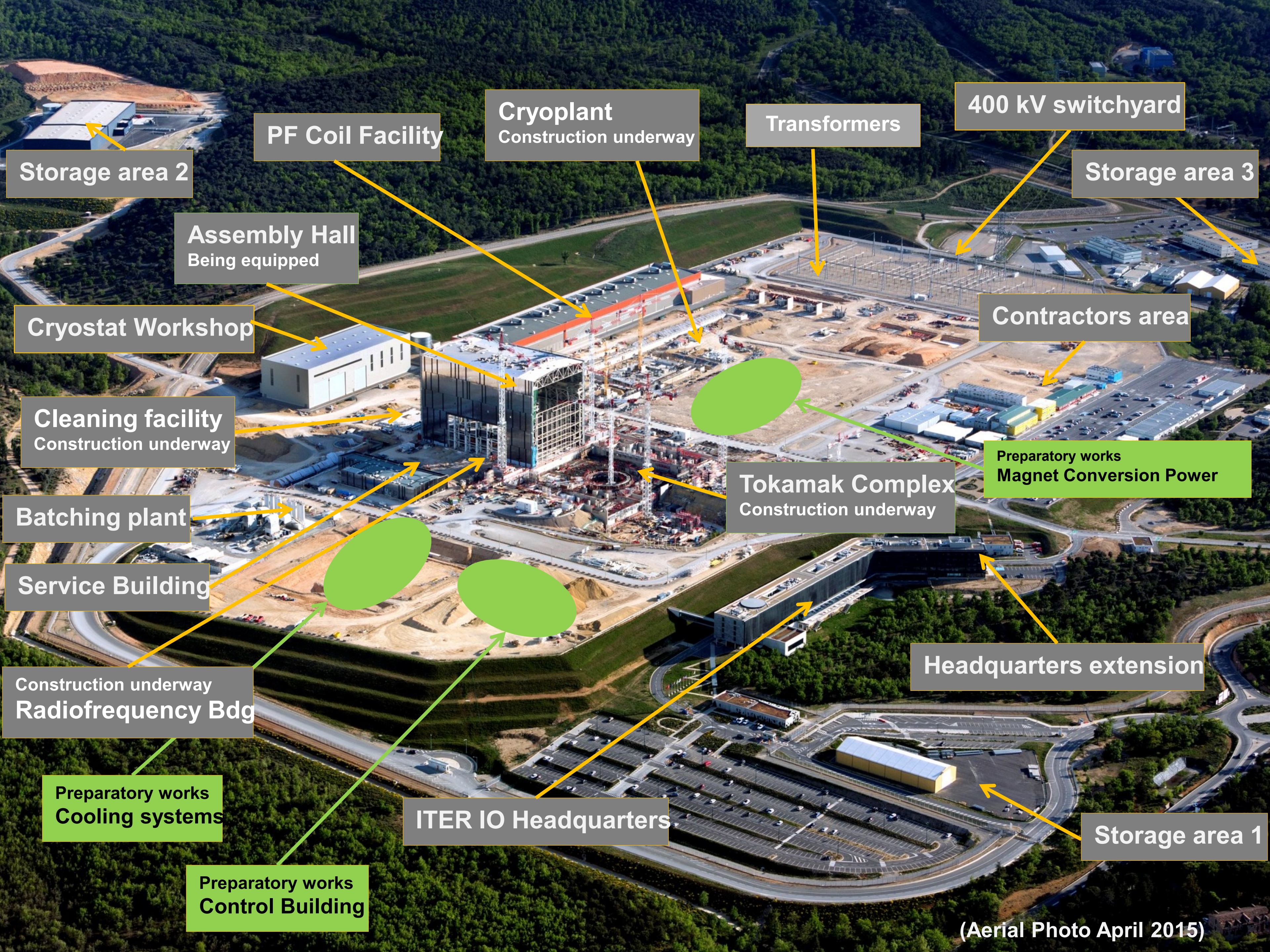
India www.iter-india.org

Japan http://www.naka.jaea.go.jp/ITER/index.html

Korea http://www.iterkorea.org/

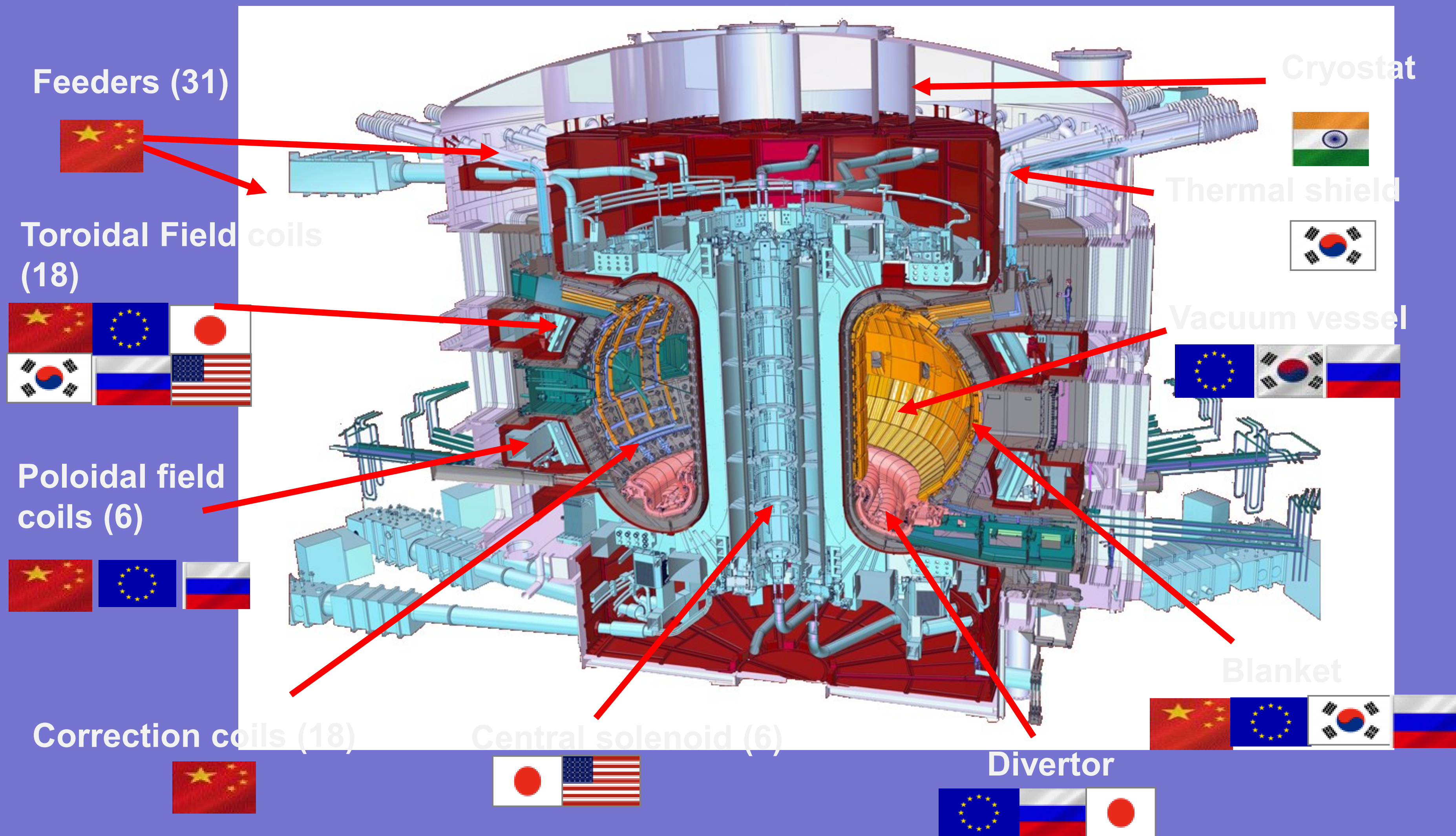
Russia http://iterrf.ru/

USA https://www.usiter.org/


Storage area 2
PF Coil Facility
Cryoplant
Construction underway
Transformers
400 kV switchyard
Storage area 3
Assembly Hall
Being equipped
Cryostat Workshop
Contractors area
Cleaning facility
Construction underway
Preparatory works
Magnet Conversion Power
Tokamak Complex
Construction underway
Batching plant
Service Building
Headquarters extension
Construction underway
Radiofrequency Bdg
Preparatory works
Cooling systems
ITER IO Headquarters
Storage area 1
Preparatory works
Control Building
(Aerial Photo April 2015)

Who manufactures what?

The ITER Members share all intellectual property



Superconducting Coil Supply:
11 in-kind Procurement Arrangements (+6 conductors)

CS with US
(General Atomics)

Pre-compression rings: EU
(EADS CASA)

PF1: RF (Efremov)

CONDUCTORS:
CN, EU, JA, KO,
RF, US

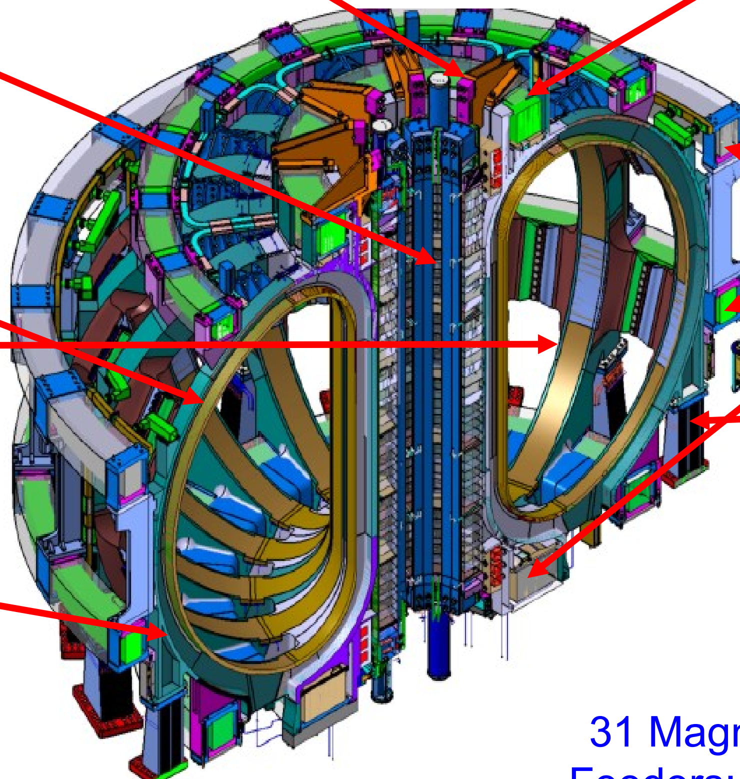
9+1 TF coils with EU
(Iberdrola/ASG/Elytt
Consort.)

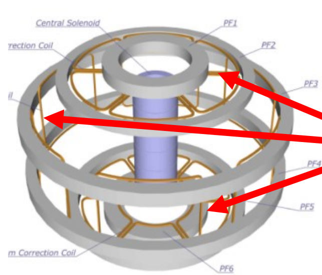
PF2-6: EU
(*ASG*)

9 TF coils with JA
(MHI)

Magnet Supports:
CN
(SWIP)

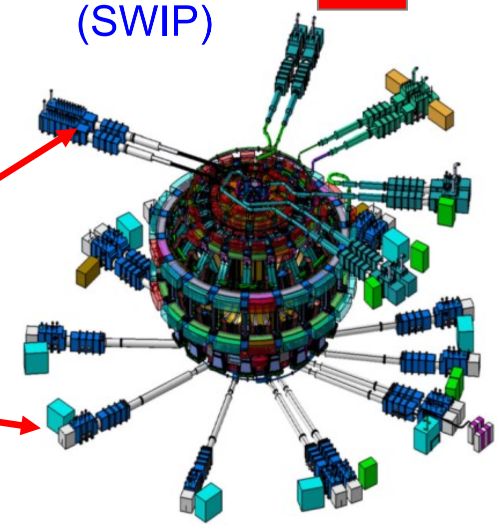
19 TF coil cases: JA
(MHI/Hyundai
Consortium)





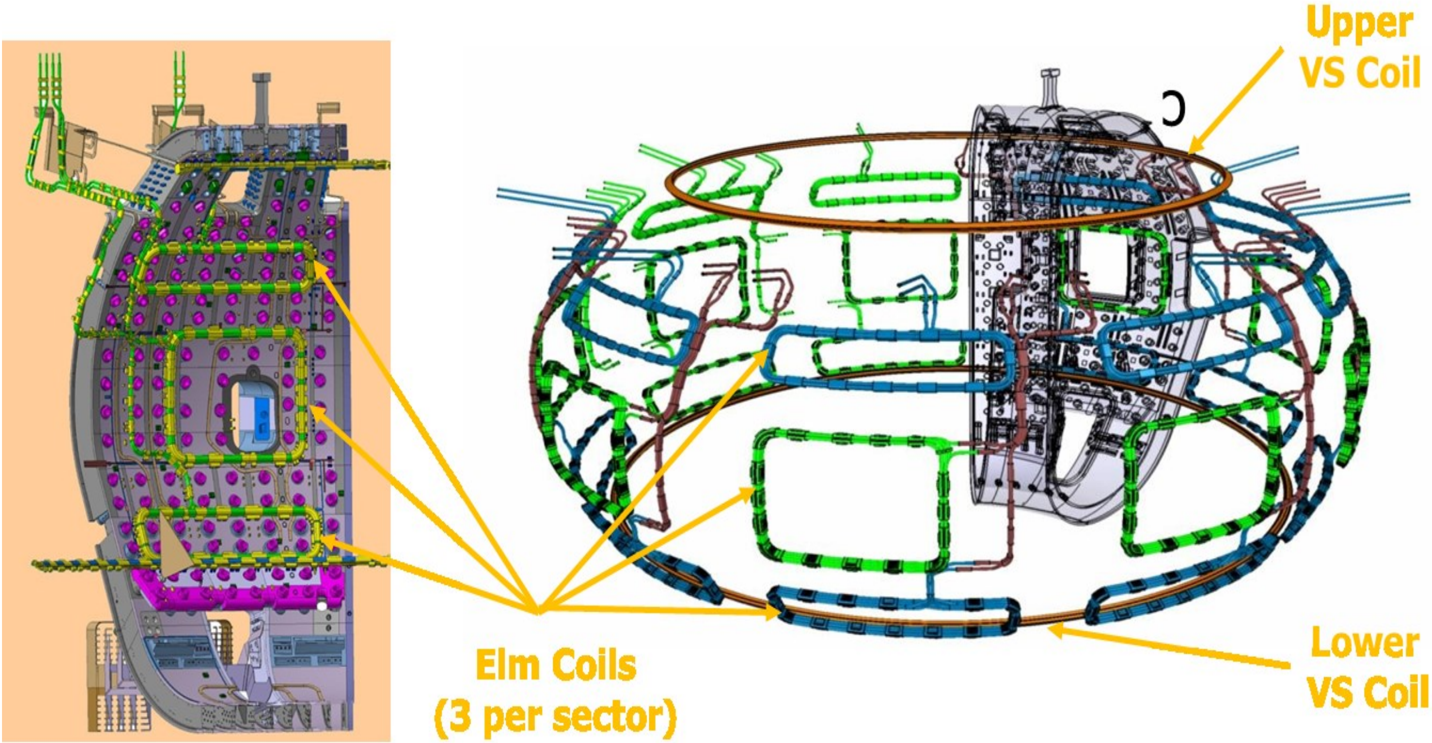
9 pairs of CCs: CN
(ASIPP)

31 Magnet
Feeders: CN
(ASIPP)



ITER In-Vessel Coils: Direct IO Procurement

- **Copper, water-cooled**, **in-vessel coils (IVCs),** attached via stubs to the outboard part of the **inner wall of the vacuum vessel** (underneath the blanket modules) have an **essential role in plasma operation.**



- The in-vessel coils comprise: **3 x 9 picture-framed, ELM coils** (controlling **Edge Localized Modes)** and **2 ring, VS coils** (controlling **Vertical Stability).**

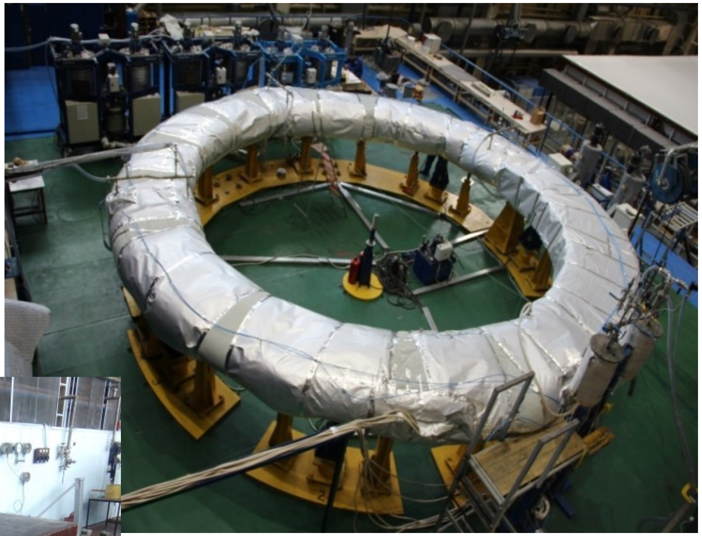
First of a Kind EU TF Winding Pack at ASG, La Spezia, Italy

Completed
July 2016

PF1 Coil Status (Efremov Institute, St Petersburg)

- **Winding of first of PF1 real double pancakes finished in August 2016.**
- **Vacuum pressure impregnation (VPI) and HV/hydraulic/leak tightness tests of PF1 dummy double pancake completed in July 2016**

PF1 real DP winding



Dummy winding (left) and dummy DP impregnation

Figures courtesy of Efremov

Winding facility & PF5

Manufacturing progress

USA

General Atomics is fabricating the 1000-ton Central Solenoid (CS). In April 2016, winding of the first CS module was completed.

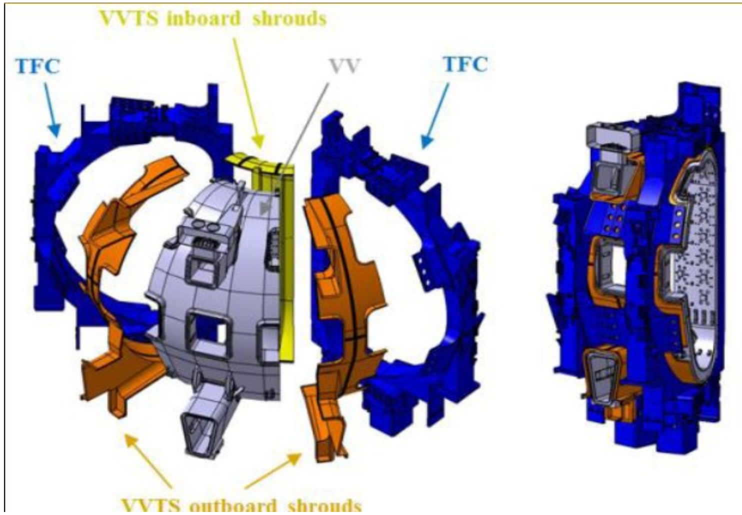
Module tooling stations are in place and being commissioned, including the heat treatment furnace shown here.

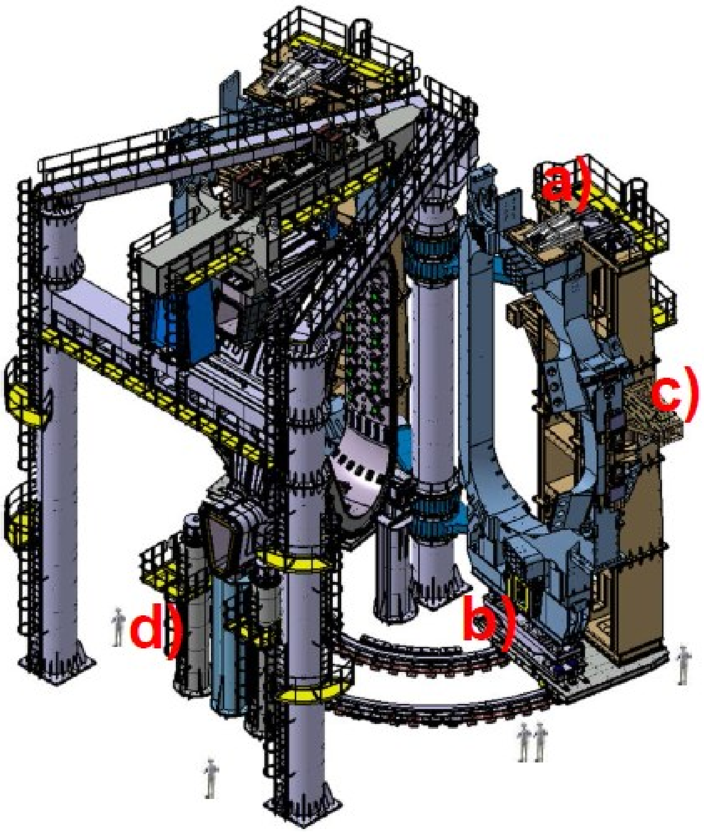
Major Assembly Tools

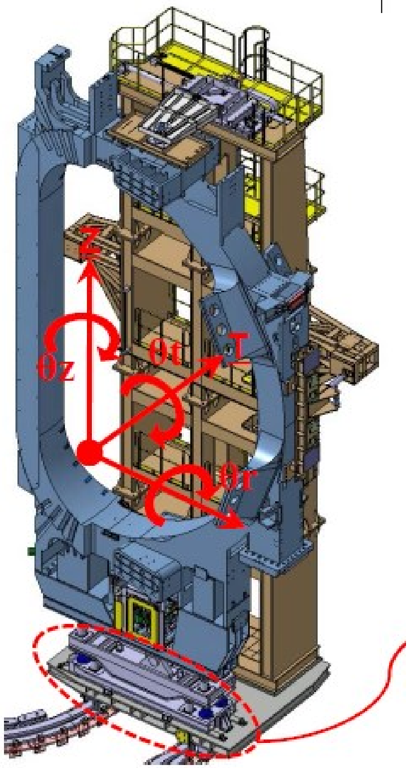
EXAMPLE:

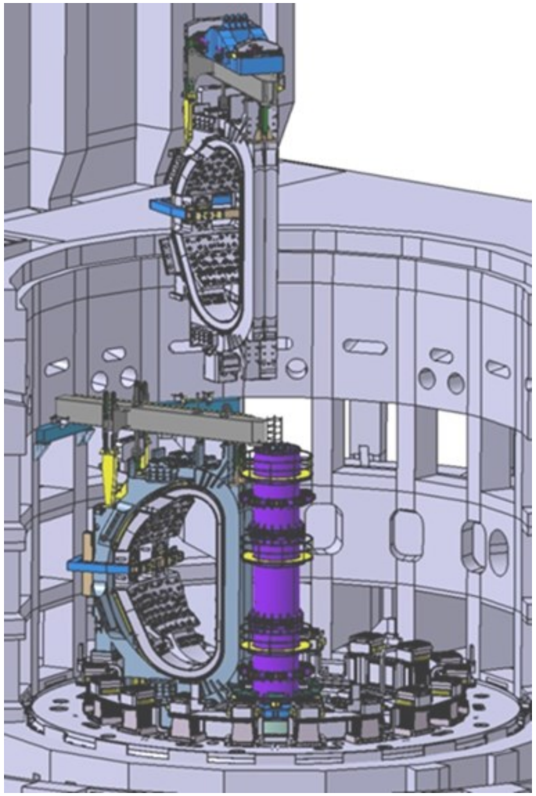
- 2 TF coils/ VV and Thermal Shield assembled to 1/9 sector on SubSector Assembly Tool
- 1/9 sector transferred into cryostat

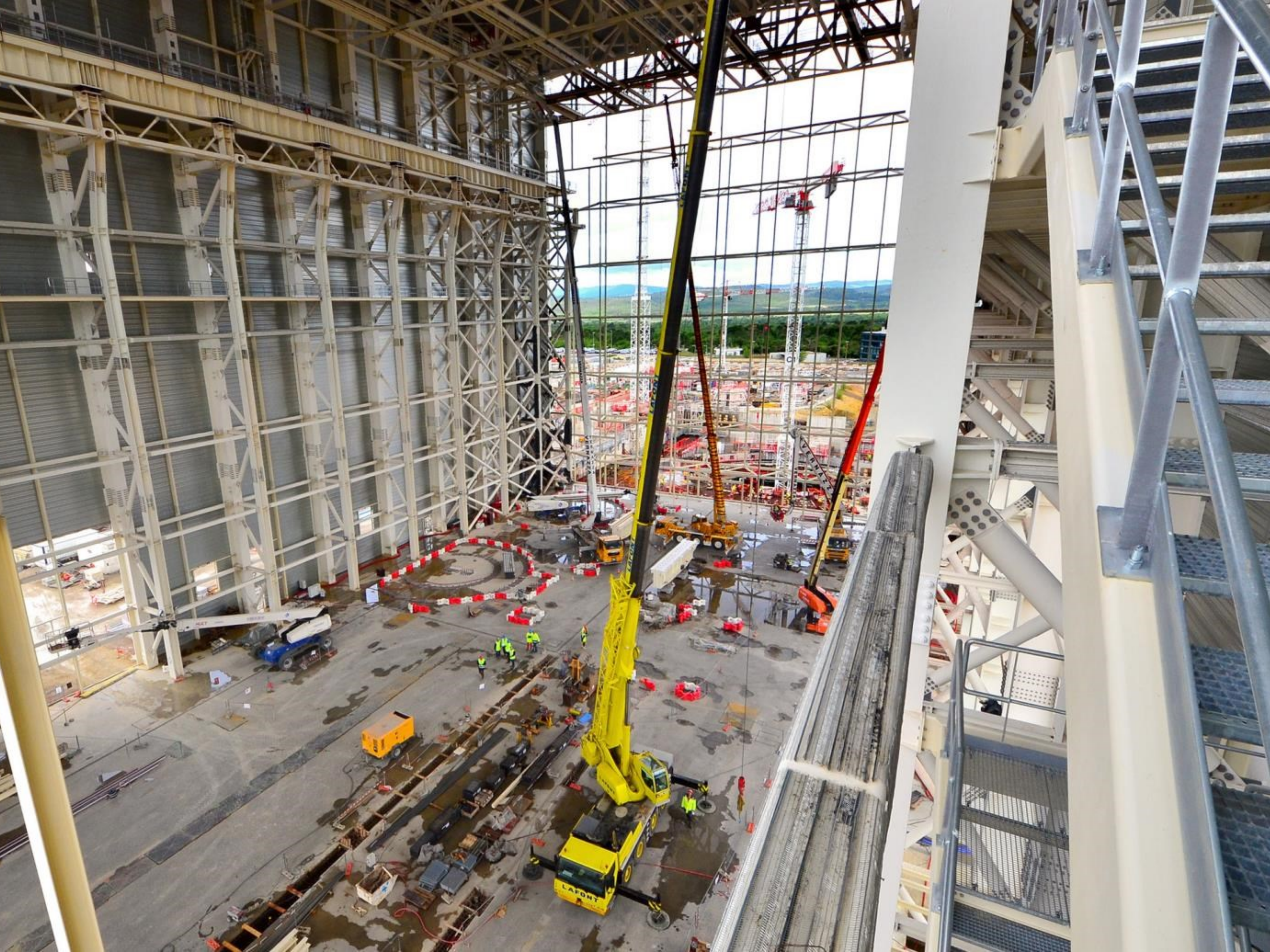
On-site delivery of tools started in 2017





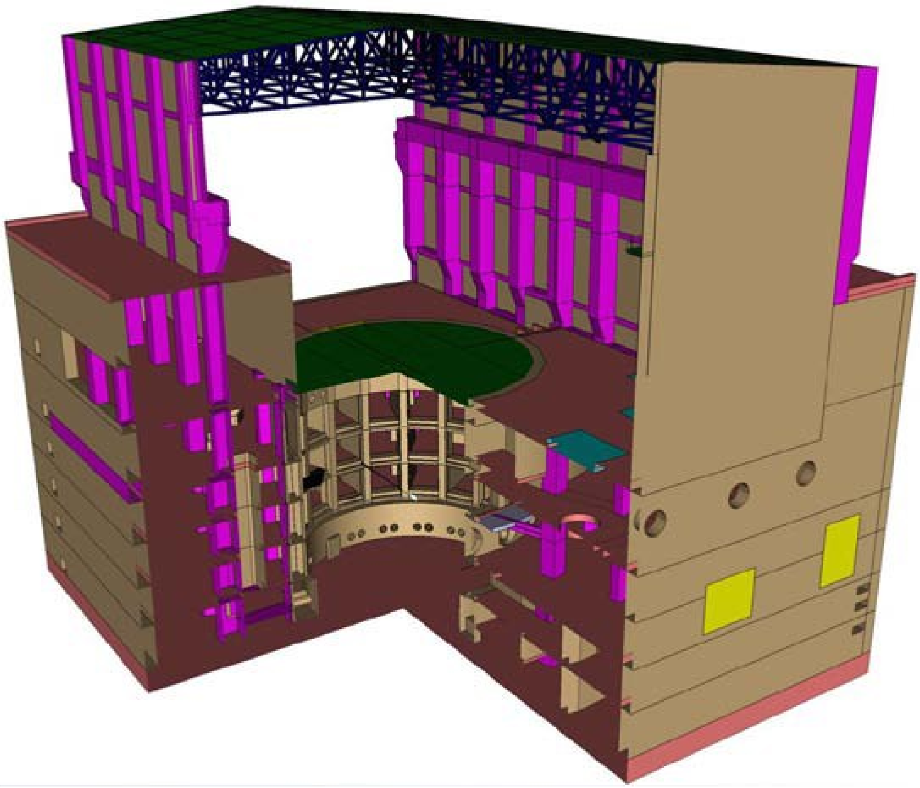
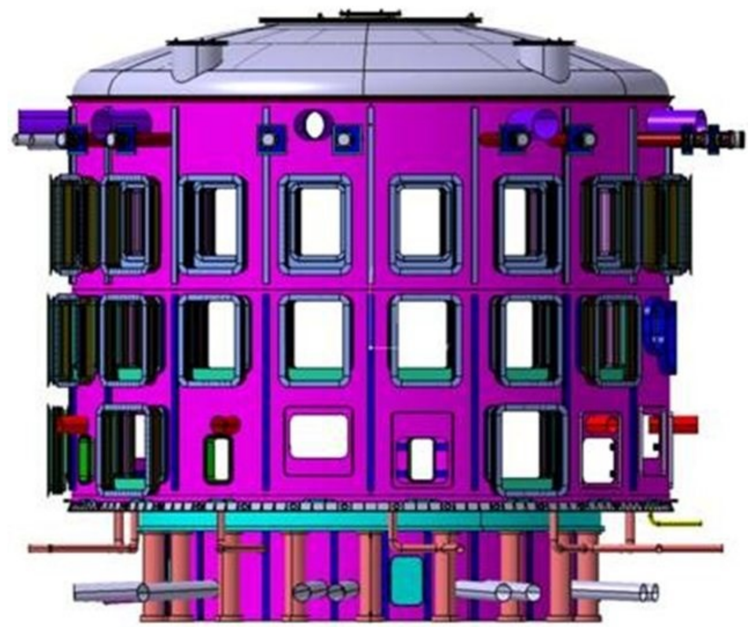





LAFONT

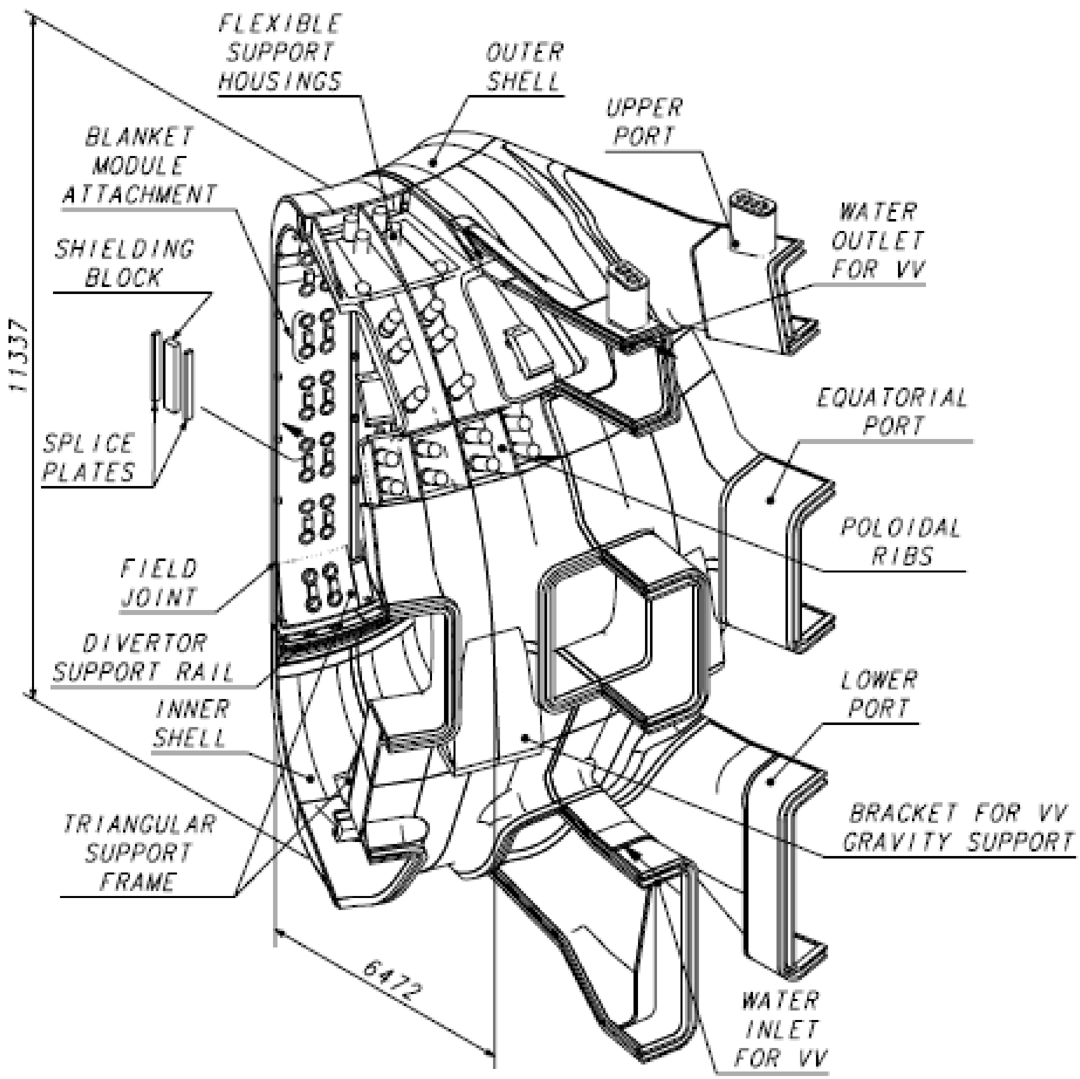

POTAIN
C1

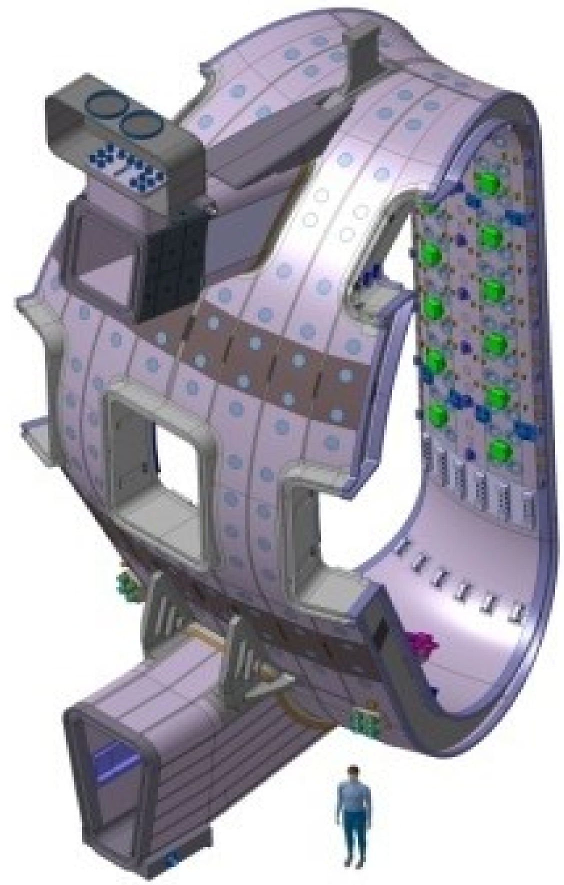
ITER Cryostat

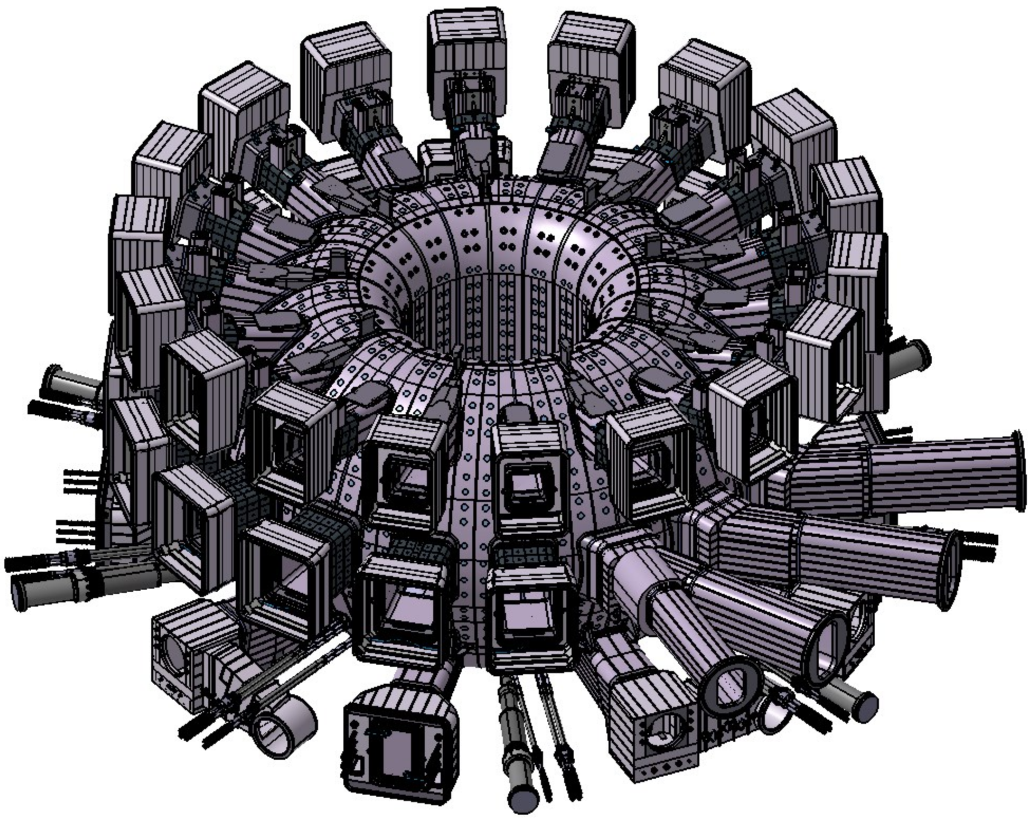
~ 10 cm stainless steel, 29.3 m x 28.6 m surrounded by bioshield (2 m thick)
Top ~ 1000t (crane limit 1500 t), total ~ 4000t
Holds 2 bars in case of accident
VVPS – vacuum vessel pressure suppression system
(cylinder 46 x Ø 6 m with water, to condense steam)

ITER Vacuum Vessel





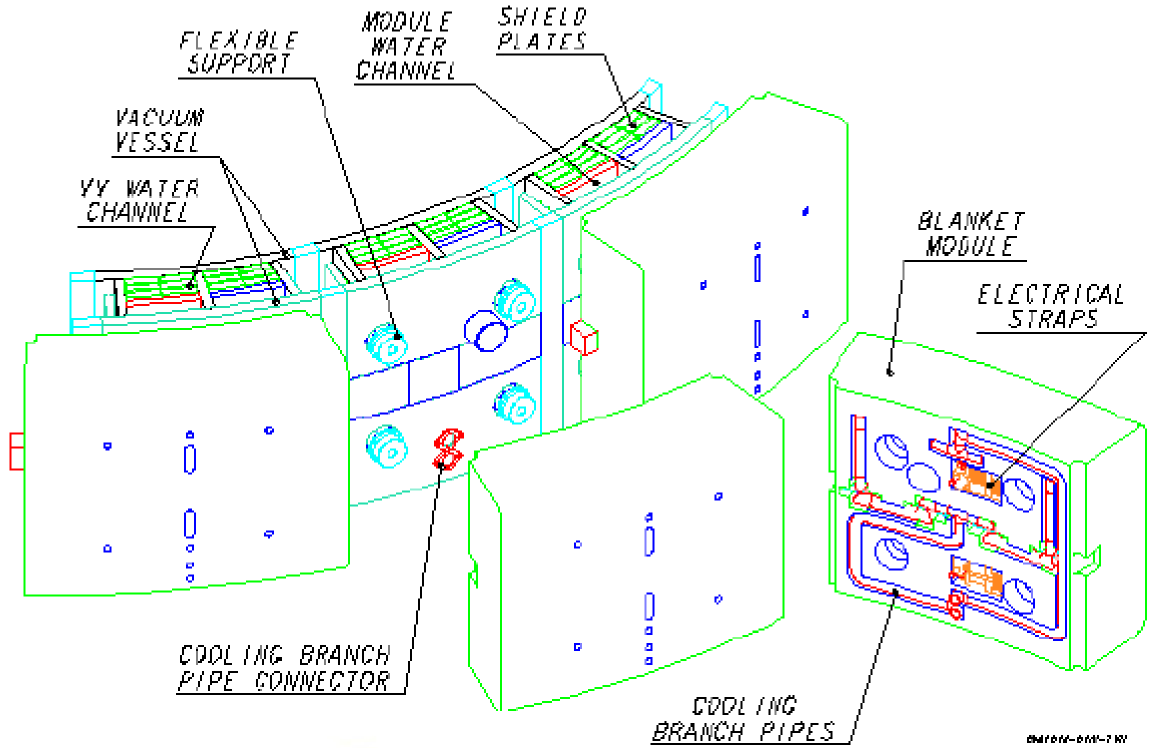
Vacuum Vessel Mass Comparison

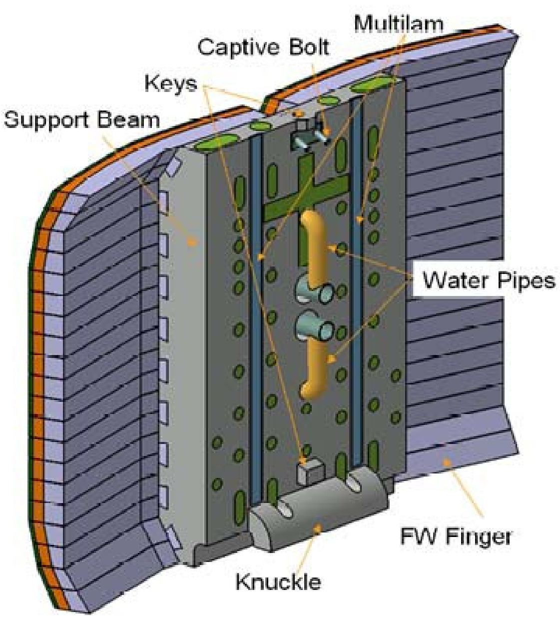


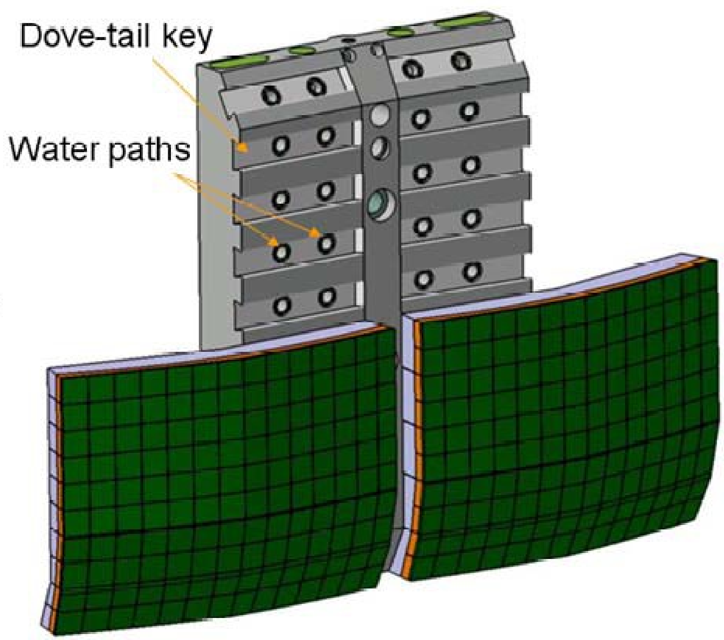
VV & In-vessel components mass: ~8000 t
19.4 m outside diameter – 11.3 m tall

Eiffel Tower mass: ~7300 t
324 m tall
(Completed 1889)

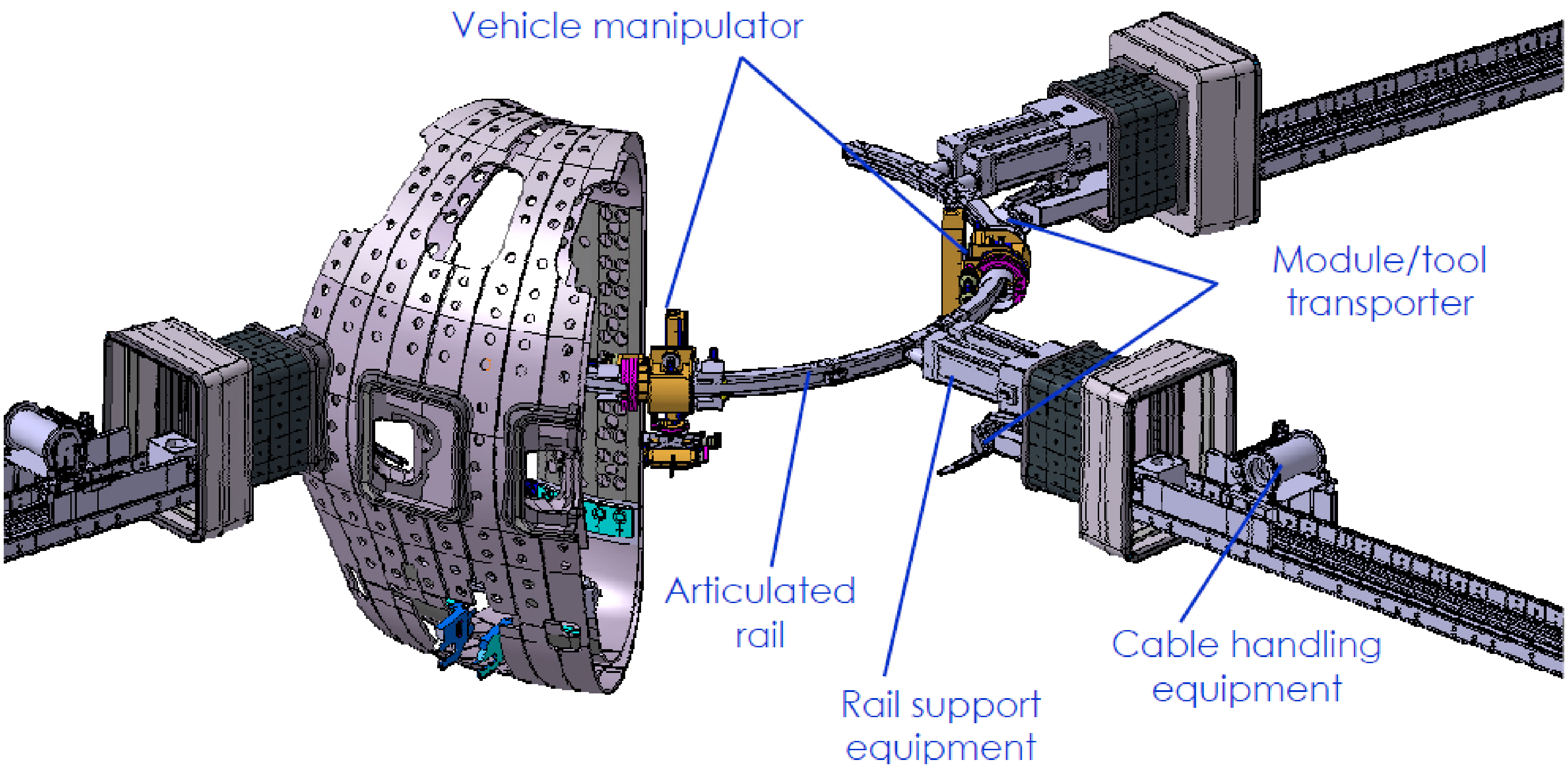
ITER blanket and the first wall

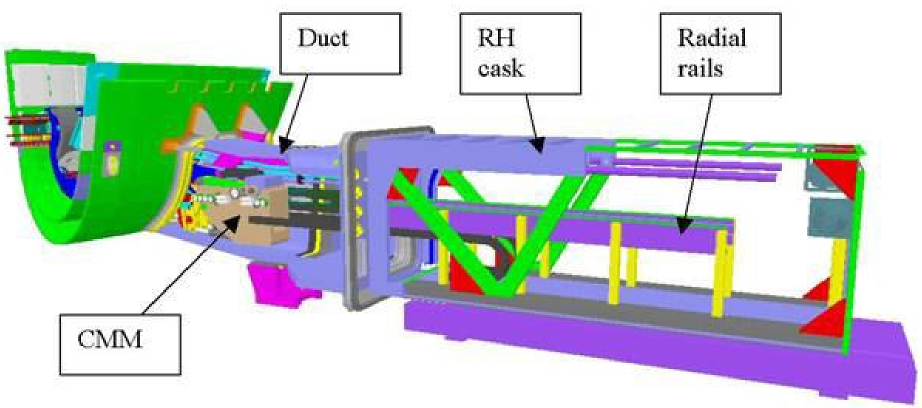


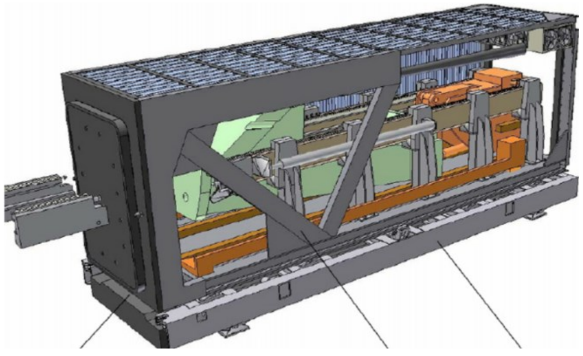




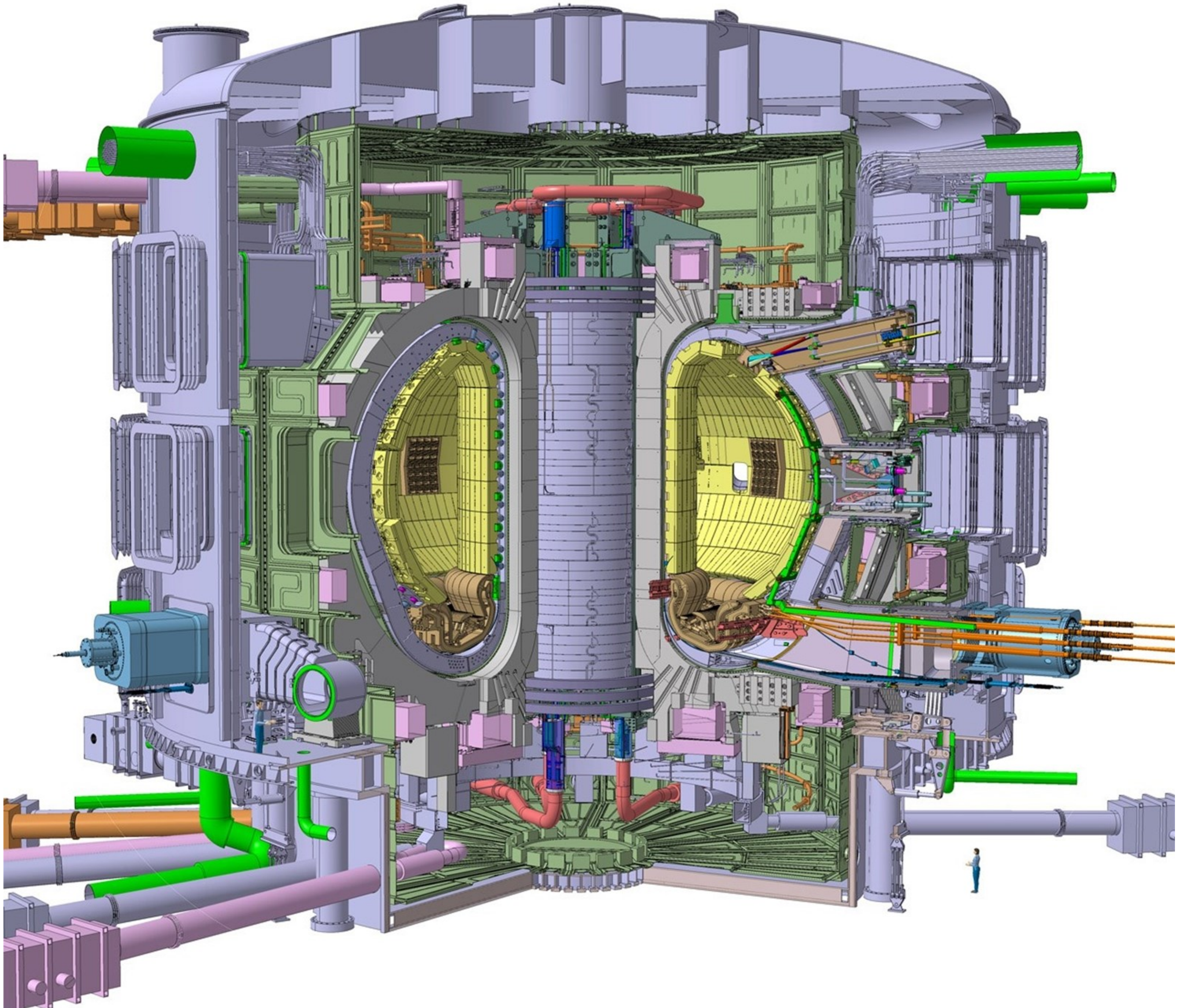
ITER – remote handling



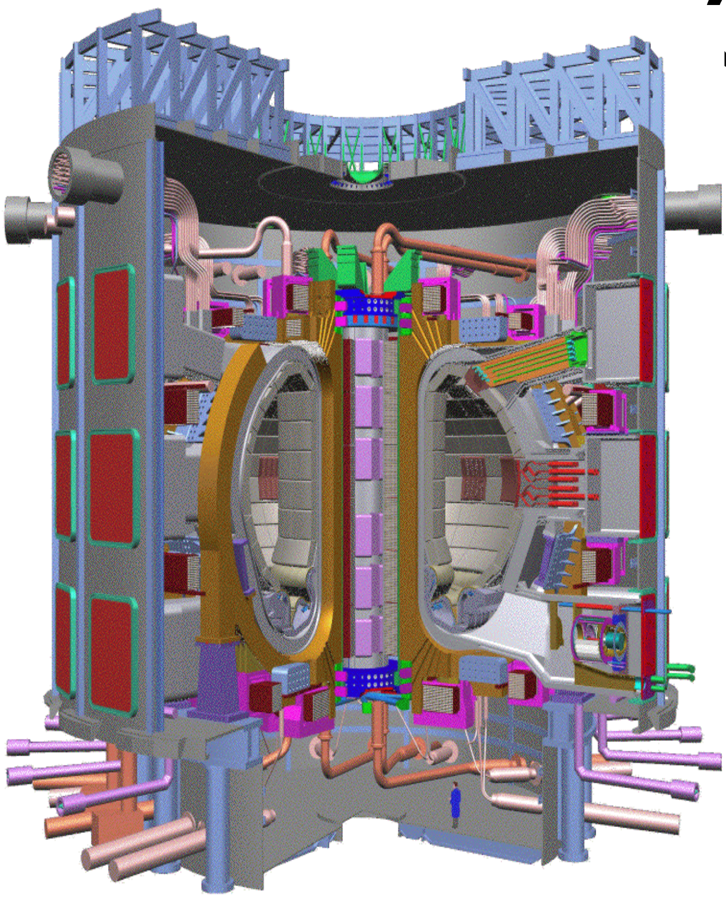




ITER - the integrated experiment



ITER Tokamak - Mass Comparison



ITER Machine mass:
~23000 t
28 m diameter x 29m tall

Aircraft carrier Charles de Gaulle mass:
~38000 t (empty)
261 m long
(Commissioned 2001)

Manufacturing progress

Korea

At Hyundai Heavy Industries, where 2 of 9 vacuum vessel sectors are under construction, welding on the upper section of the inner shell for Sector #6.

Inner shell assembly of a lower port stub extension for the vacuum vessel.

convois très exceptionnels

Assembly Hall

53 metres above the building's basemat a double overhead crane is installed

Lifting operations
.

Complete with gear-motors, wheels, braces, electrical gear, etc., the beam now weighs 186 tons.

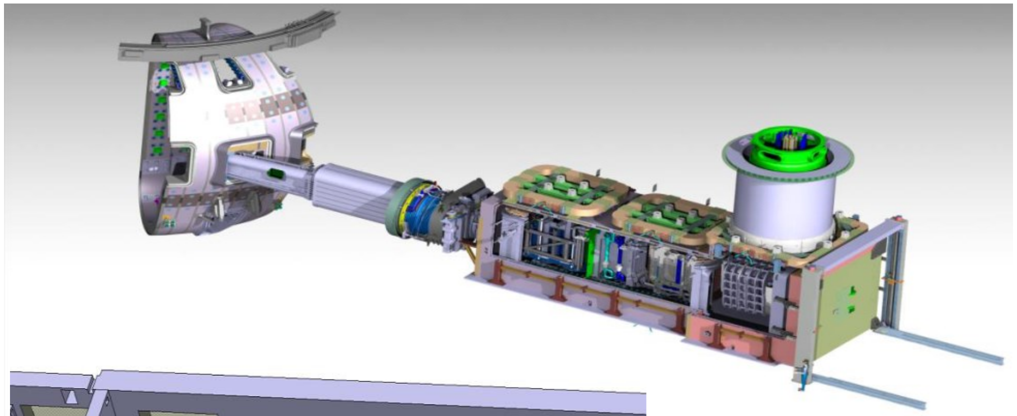
Each pair of cranes will have a lifting capacity of 750 tons.

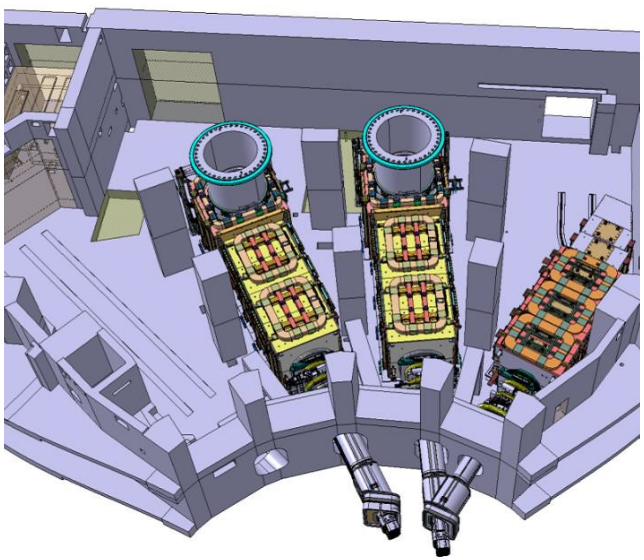
The 4 beams and 2 of 4 trolleys (100 t.) are installed.

Before being integrated in the machine, the components will be prepared and pre-assembled in this 6,000 m², 60-metre high building. The Assembly Hall is equipped with a double overhead travelling crane with a total lifting capacity of 1,500 tons.

Engineering innovation: world's largest single-platform cryogenics plant

ITER – N-NBI systems





- **2 (+1) HNB: Heating Neutral Beam**
- **1 DNB: Diagnostic Neutral Beam**
- **NBTF: Neutral Beam Test Facility**

• 2 HNBs (+1)			
• P_{beam}	=	16.5	MW
• I	=	40	A
• V	=	1	MV
• T_{pulse}	=	3600	s

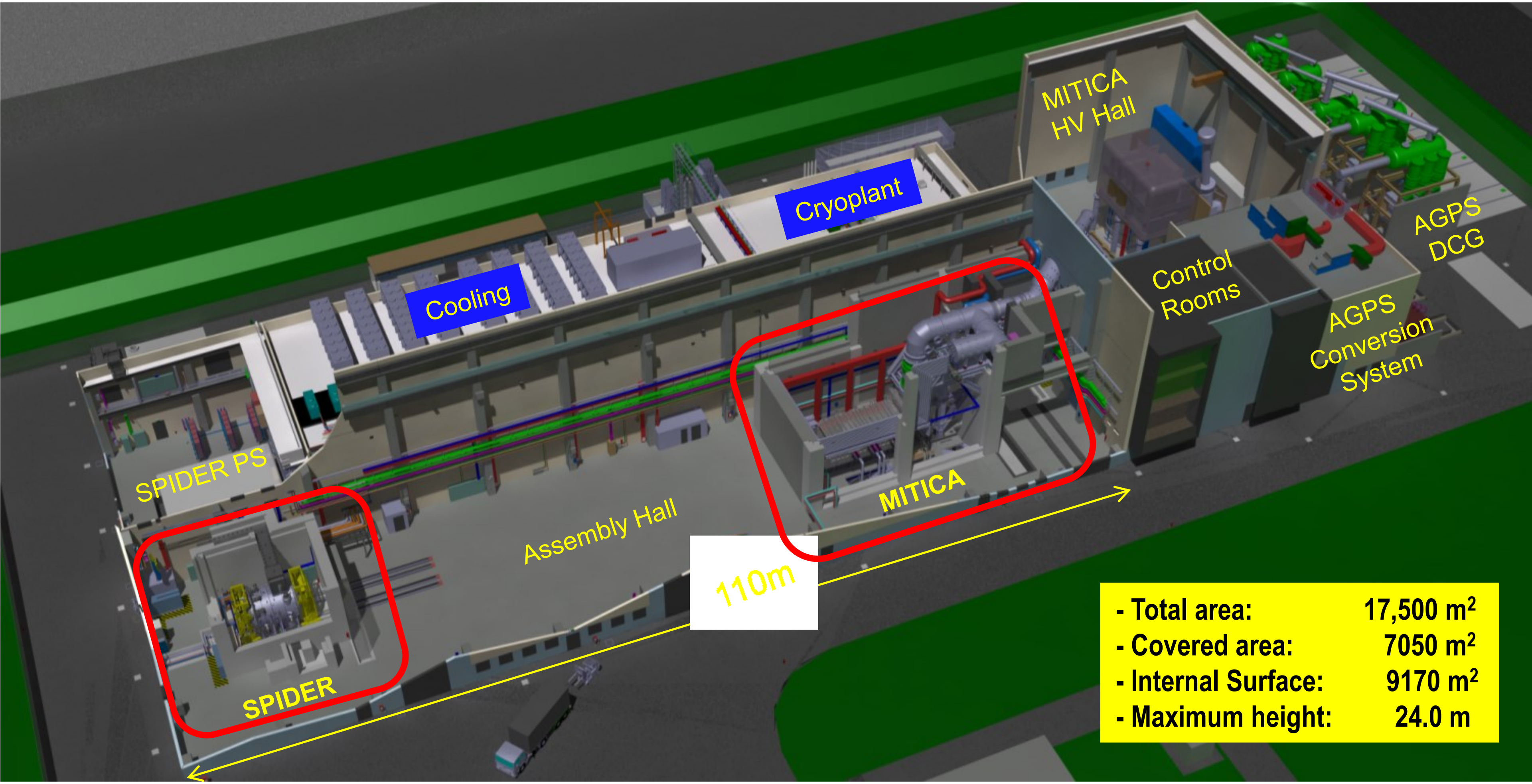
EUDA & JADA procurement

•1 DNB			
• I	=	60	A
• V	=	0.1	MV
• T_{pulse}	=	3s every 20s	
• Modulation	=		5Hz

INDA procurement

ITER HNB necessary for L to H mode transition

PRIMA: Neutral Beam Test Facility



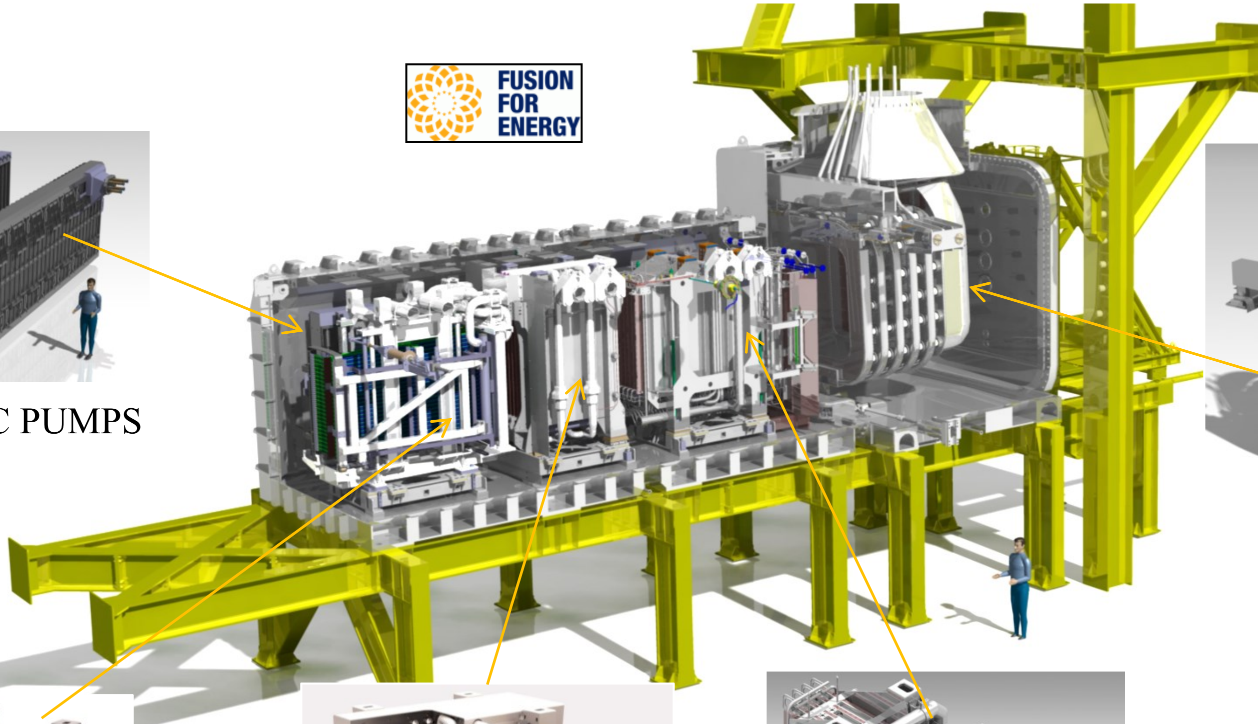
- Total area:	17,500 m^2
- Covered area:	7050 m^2
- Internal Surface:	9170 m^2
- Maximum height:	24.0 m

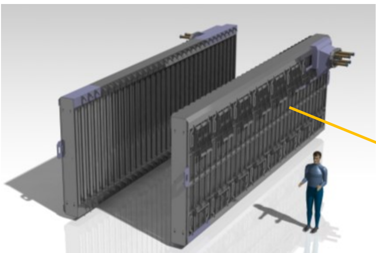
Prima hosts the two experiments: the negative ion source **SPIDER** and the 1:1 prototype of the ITER injector **MITICA**

Each experiment is inside a concrete biological shield against radiation and neutrons produced by the injectors

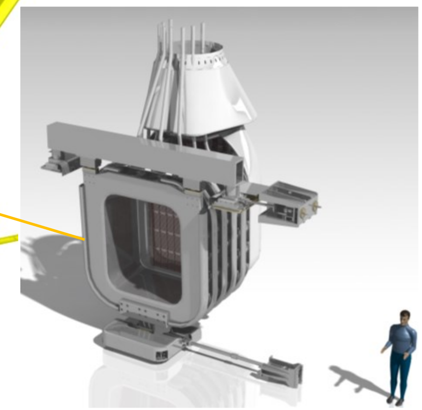
Thanks to these shielding the assembly/maintenance area will be fully accessible also during experiments

MITICA Injector Components



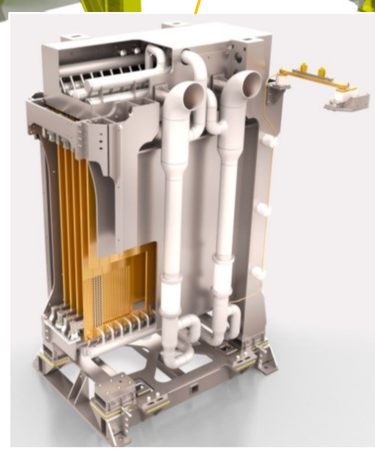


CRYOGENIC PUMPS

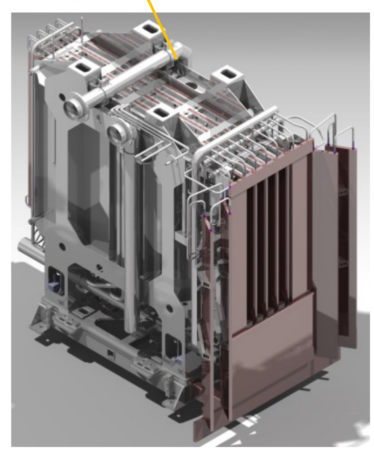


BEAM SOURCE

CALORIMETER



RESIDUAL ION DUMP



NEUTRALIZER

- The design of BLC was completed at the beginning of 2016
- Start of procurement within 2016

Building near Padova, Italy (MITICA)

Buildings, auxiliaries and power grid are provided by Italian Government

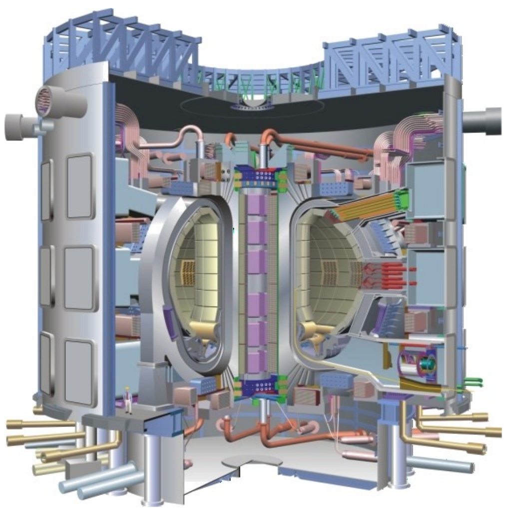
- Oct 2012: start of building erection
- Sept 2014: delivery of the first 2 buildings
- Sept 2015: delivery of all buildings
- Now auxiliaries under commissioning and Site Acceptance tests

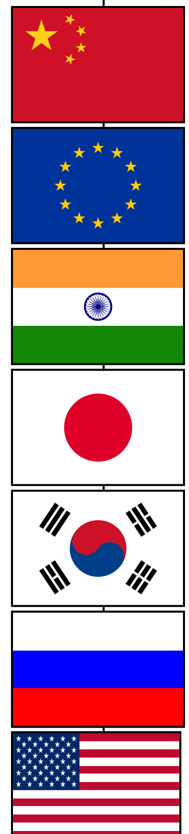
2. EU/Japan Broader Approach (BA)

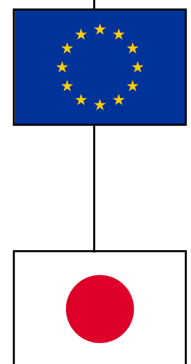
ITER and the broader approach EU/Japan

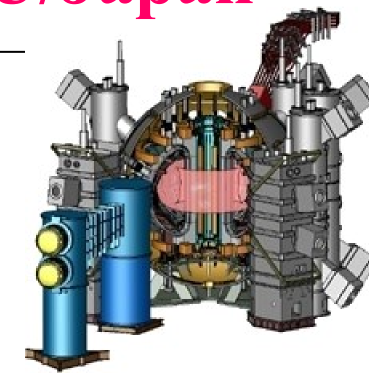
ITER

B.A.



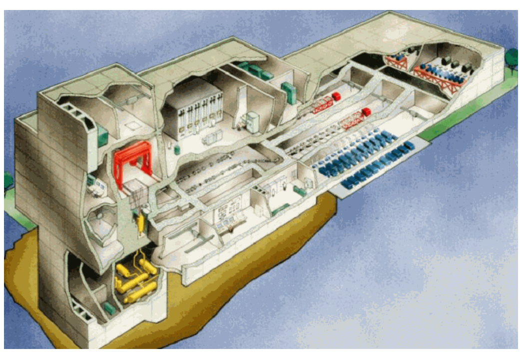






47% JT60-SA

31% IFERC



22% IFMIF-EVEDA

~5 billions €

~0,68 billions €

Broader Approach(BA)

- "Broader approach" (EU – Japan) signed February 2007
- direct financial and expert support of EU to projects sited in Japan
- 3 projects: IFMIF-EVEDA, IFERC, Satellite tokamak

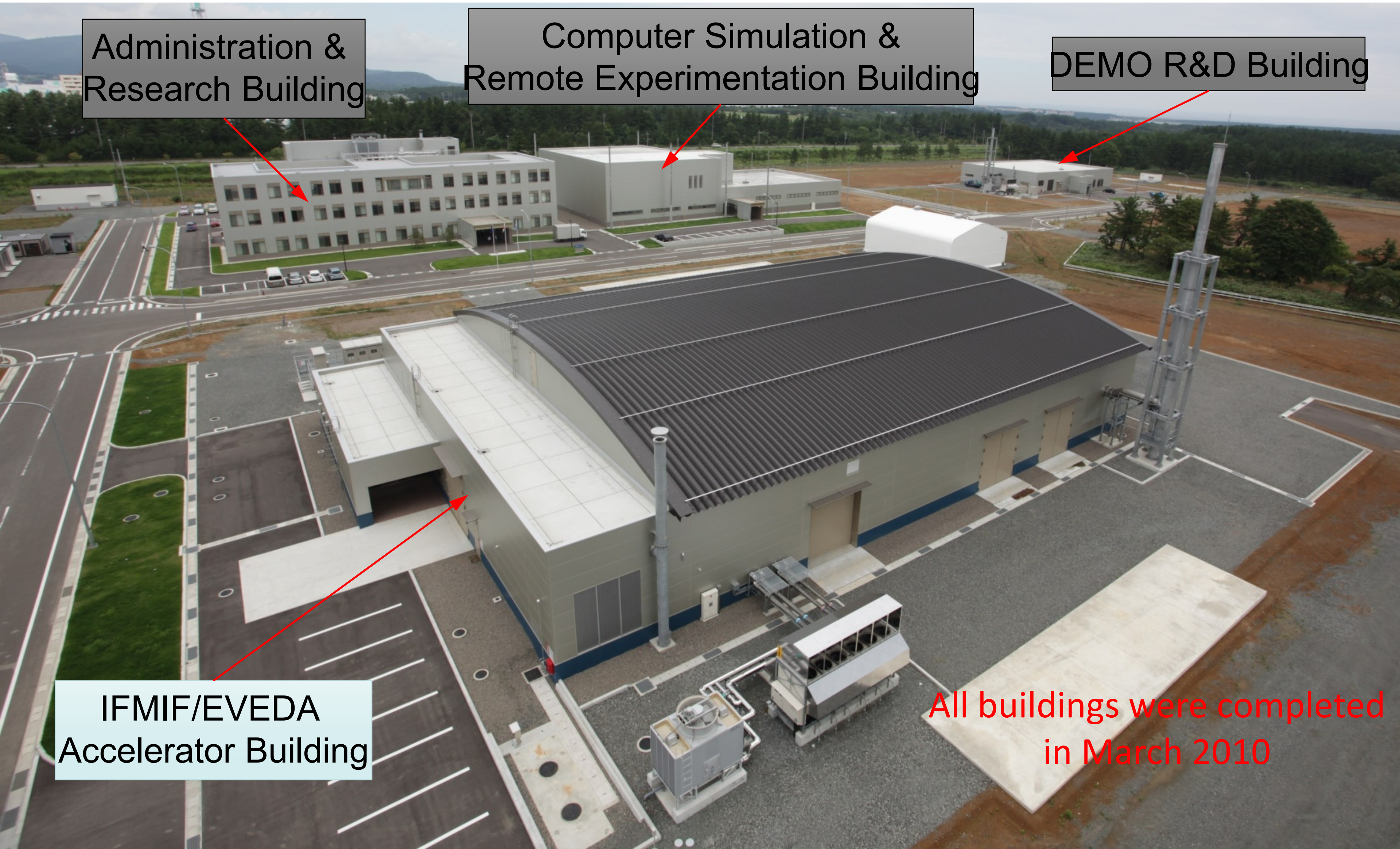
IFMIF-EVEDA: Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility

motivation: fluence in ITER (total number of fusion neutrons) will be much lower that in the fusion power plant. For research of material damage due to neutrons, another facility has to be built

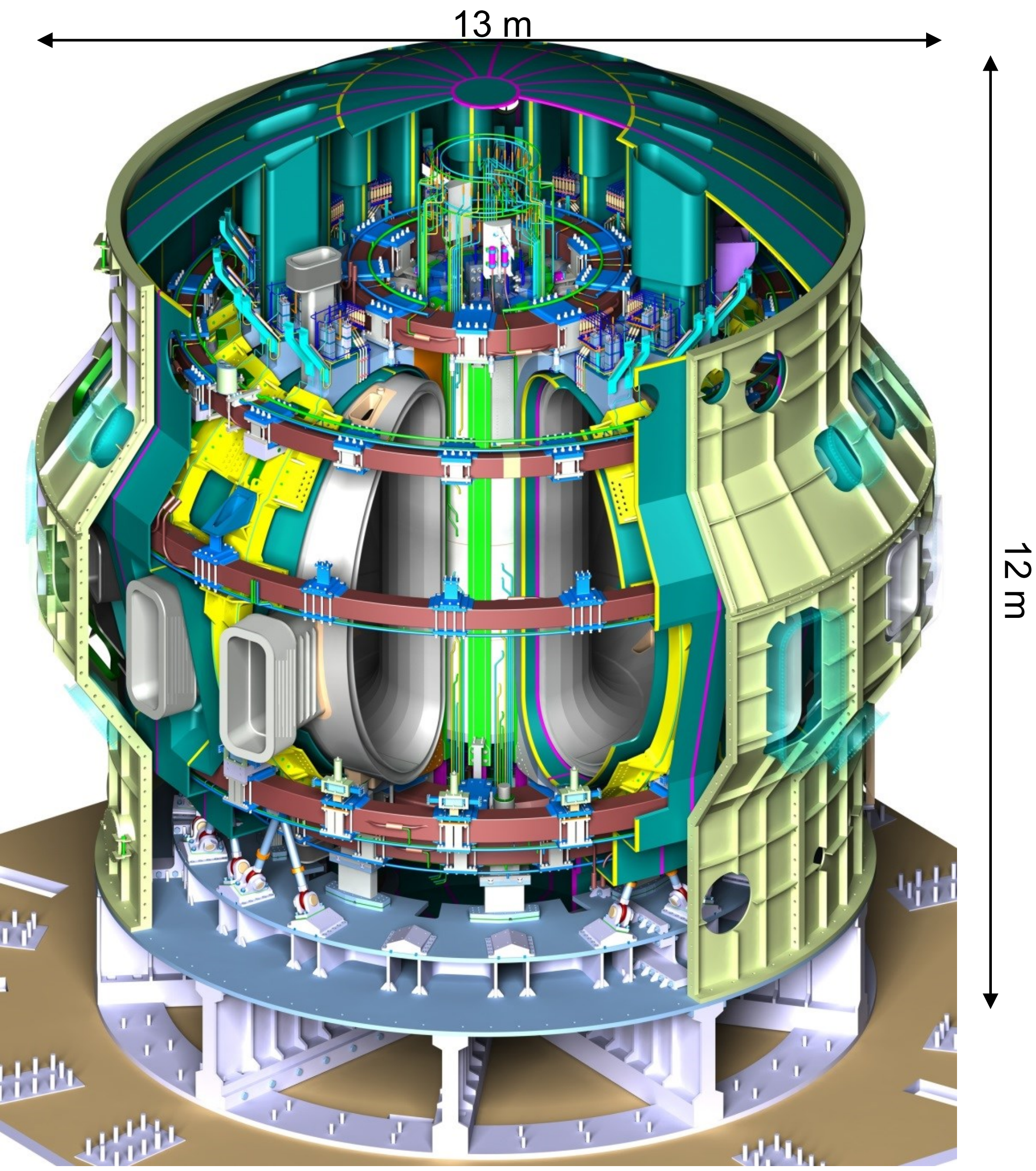
IFERC: International Fusion Energy Research Center in Japan with three major tasks – DEMO design and R&D coordination, Computational simulation, ITER Remote experimentation

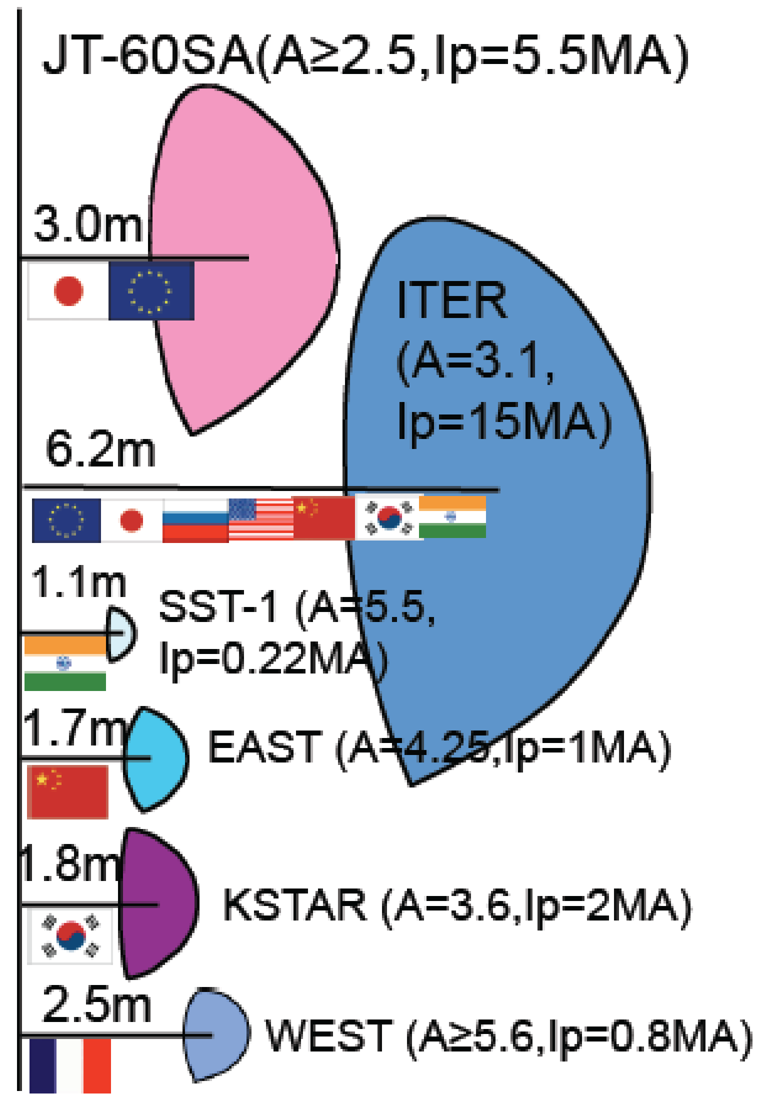
Satellite tokamak: JT-60SA, superconductive tokamak of JET size, necessary for development of operation scenarios and physics (no tritium)

Broader approach – Rokkasho site



JT-60SA (Super Advanced) Project





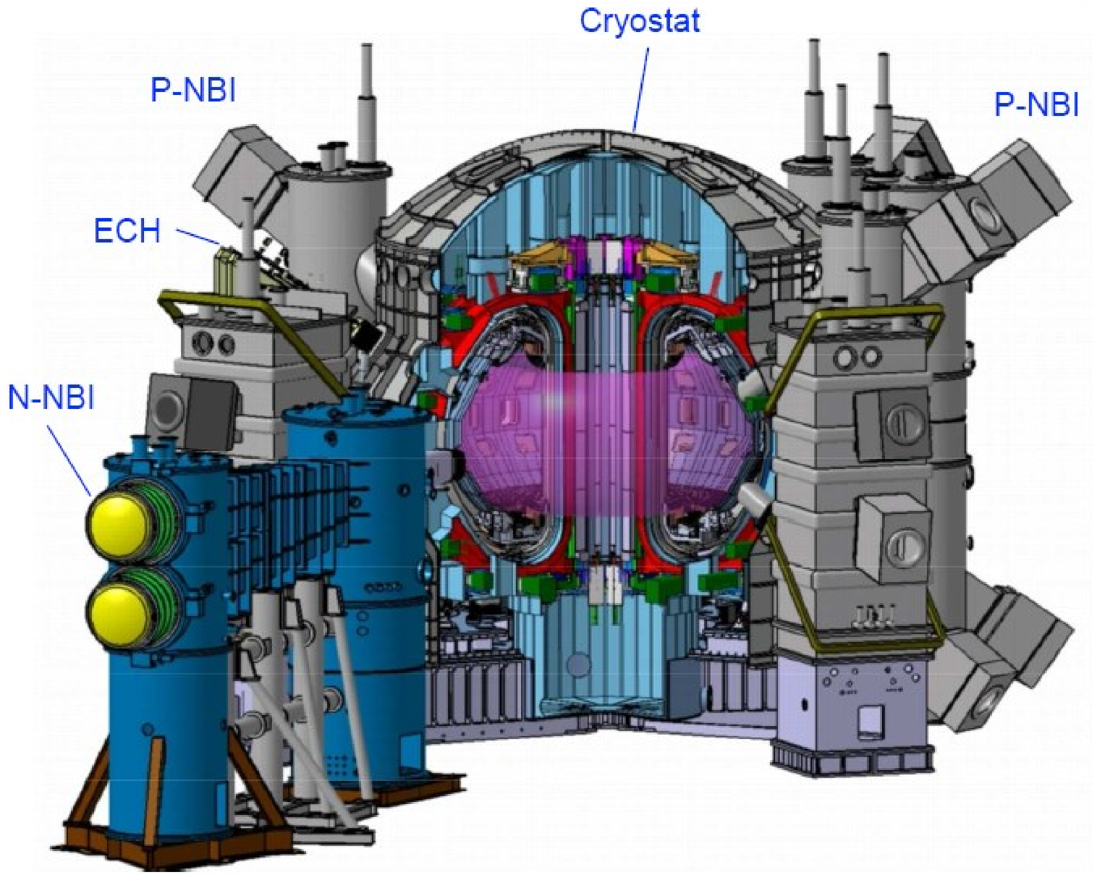
Broader Approach – JT60SA

Mission of the JT-60SA project is to contribute to the early realization of fusion energy by its exploitation to support the exploitation of ITER and research towards DEMO, by addressing key physics issues for ITER and DEMO.

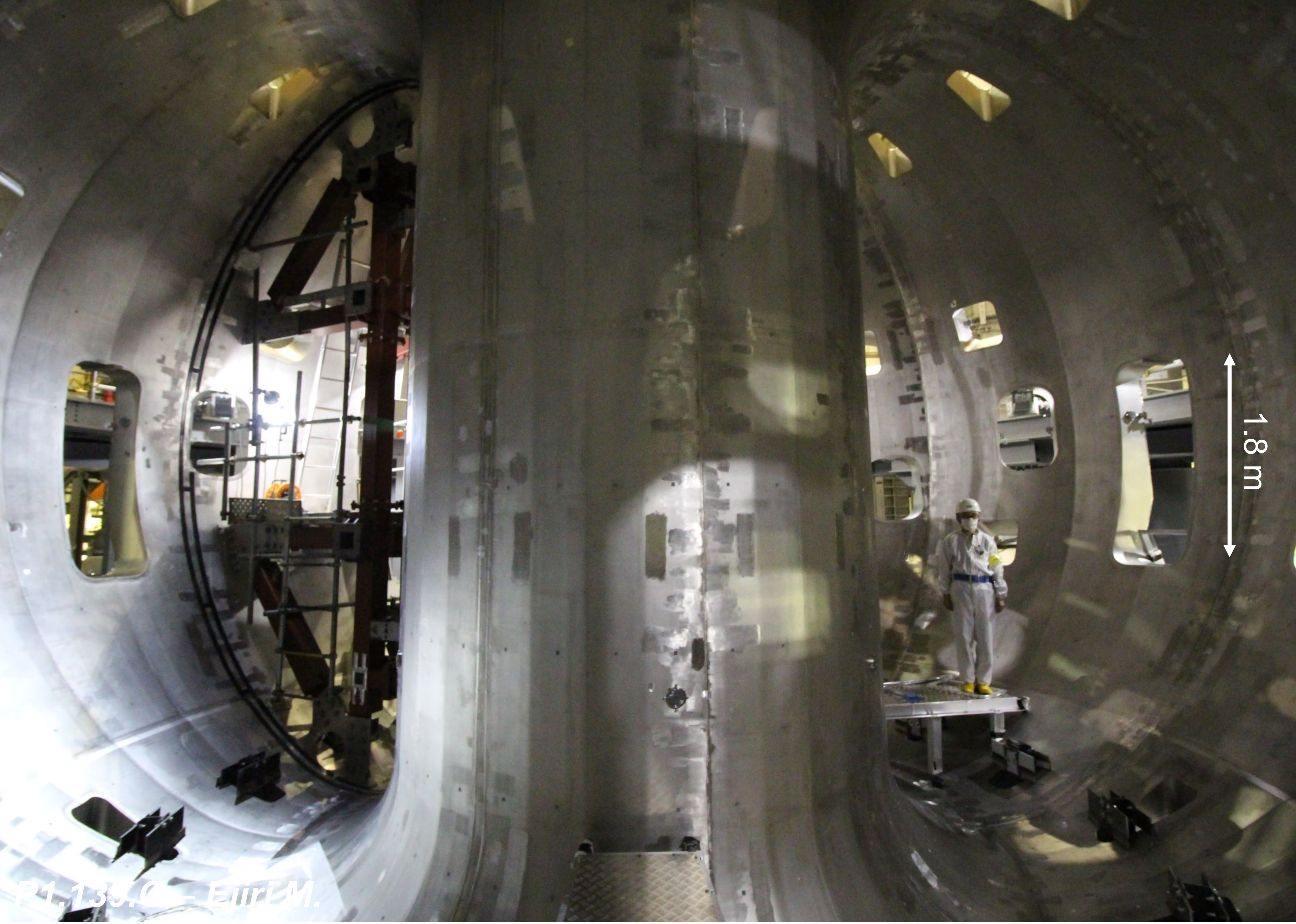
Basic machine parameters

Plasma Current	5.5 MA
Toroidal Field, B_t	2.25 T
Major Radius, R_p	2.96
Minor Radius, a	1.18
Elongation, κ_X	1.95
Triangularity, δ_X	0.53
Aspect Ratio, A	2.5
Shape Parameter, S *	6.7
Safety Factor, q_{95}	~3
Flattop Duration	100 s
Heating & CD Power	41 MW
N-NBI P-NBI ECRF	10 MW 24 MW 7 MW
Divertor wall load	15 MW/m^2

* $S = q_{95}I_p/(aB_t)$



• ***Vacuum vessel thermal shield installation progressing smoothly***



- *340° Vacuum Vessel completely assembled*

3. Materials testing facilities

How to address the materials issues for DEMO?

Technology R&D

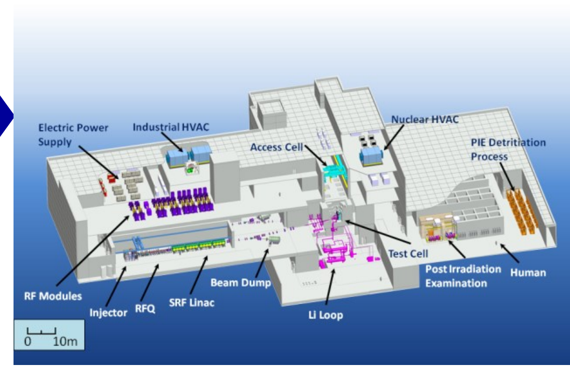
Structural Materials

Test Blanket Modules

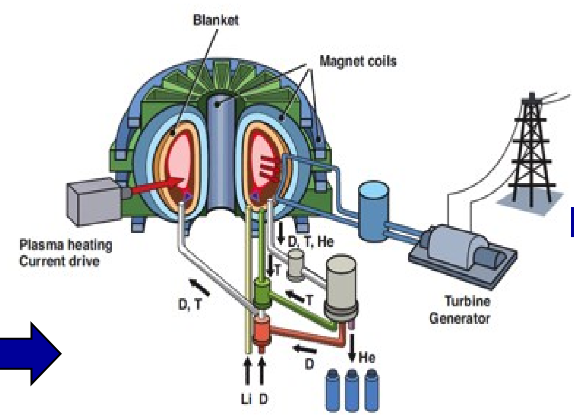
Components

- SC Magnets
- Tritium Handling System
- Plasma Facing Components
- Remote Maintenance System
- Heating System
- Safety

IFMIF



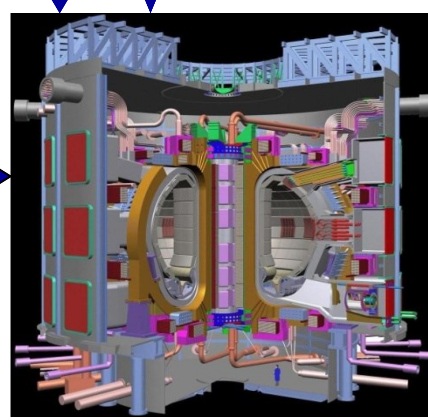
Blanket tests in ITER



DEMO

Plasma Physics R&D

- Confinement
- Impurity Control
- Stability
- …

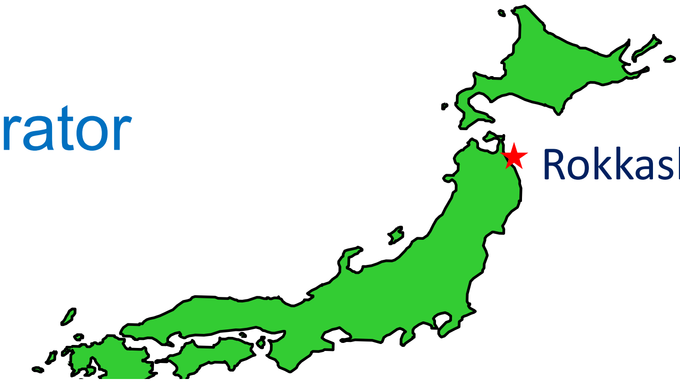


ITER

Fusion Power Plants

Current accelerator design validation (ongoing part of IFMIF/EVEDA Project)

LIPAc
Linear IFMIF Prototype Accelerator



Injector + LEBT
CEA Saclay

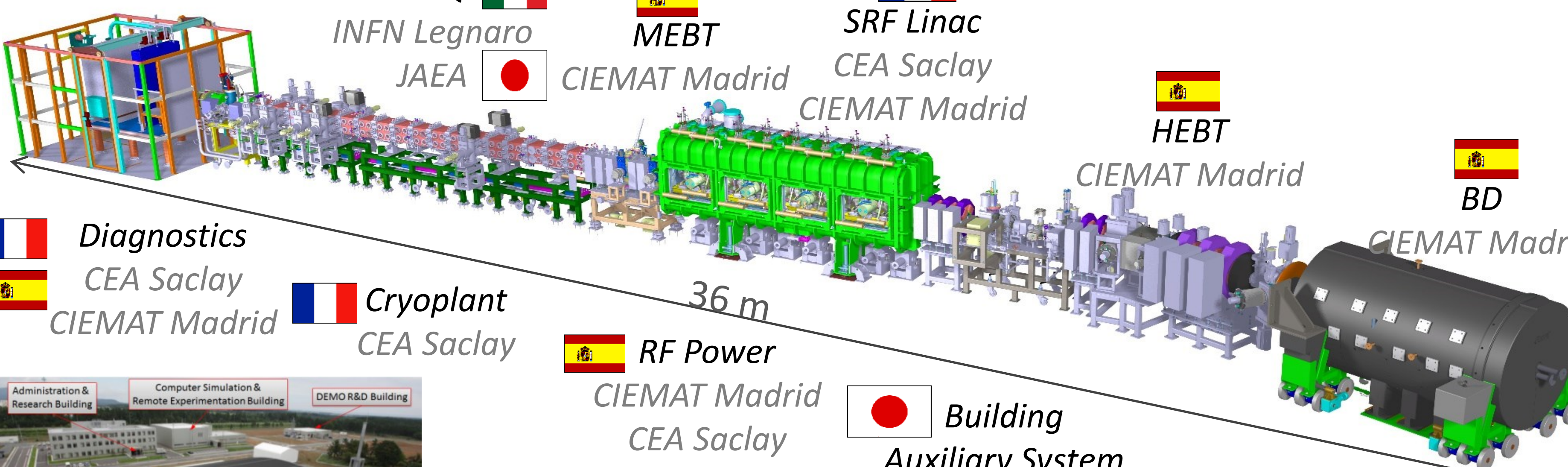
RFQ
INFN Legnaro
JAEA

MEBT
CIEMAT Madrid

SRF Linac
CEA Saclay
CIEMAT Madrid

HEBT
CIEMAT Madrid

BD
CIEMAT Madrid



Diagnostics
CEA Saclay
CIEMAT Madrid

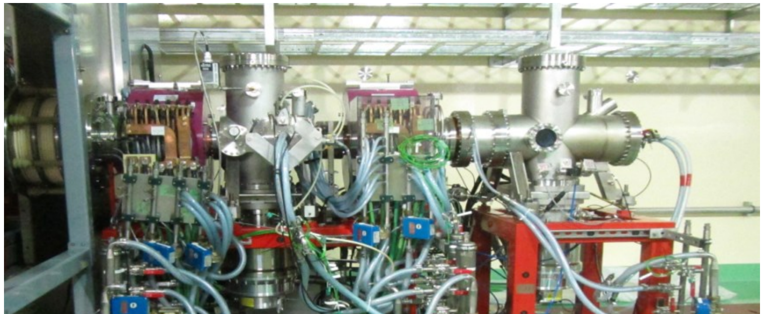
Cryoplant
CEA Saclay

RF Power
CIEMAT Madrid
CEA Saclay
SCK Mol

Building
Auxiliary System
Control system
Installation
JAEA

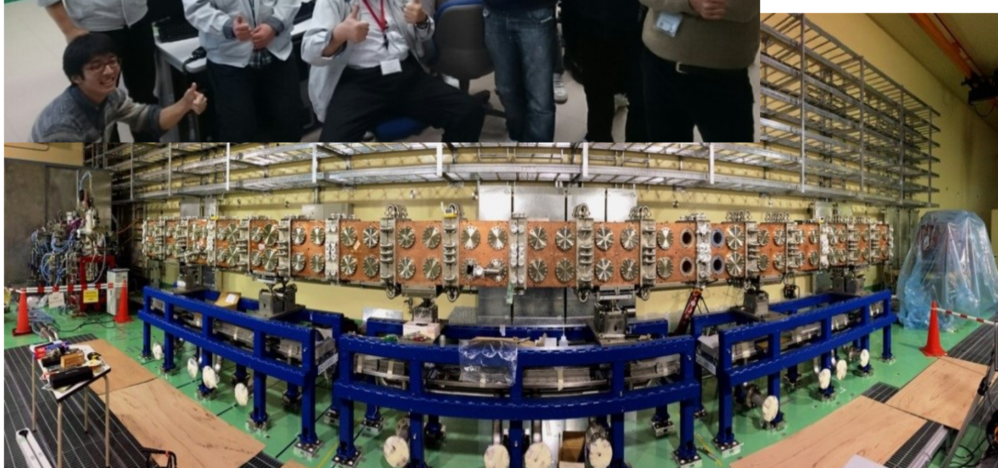
Status of LIPAc Phases (Rokkasho site)

Injector under commissioning



MEBT set up

Diagnostics Plate set up



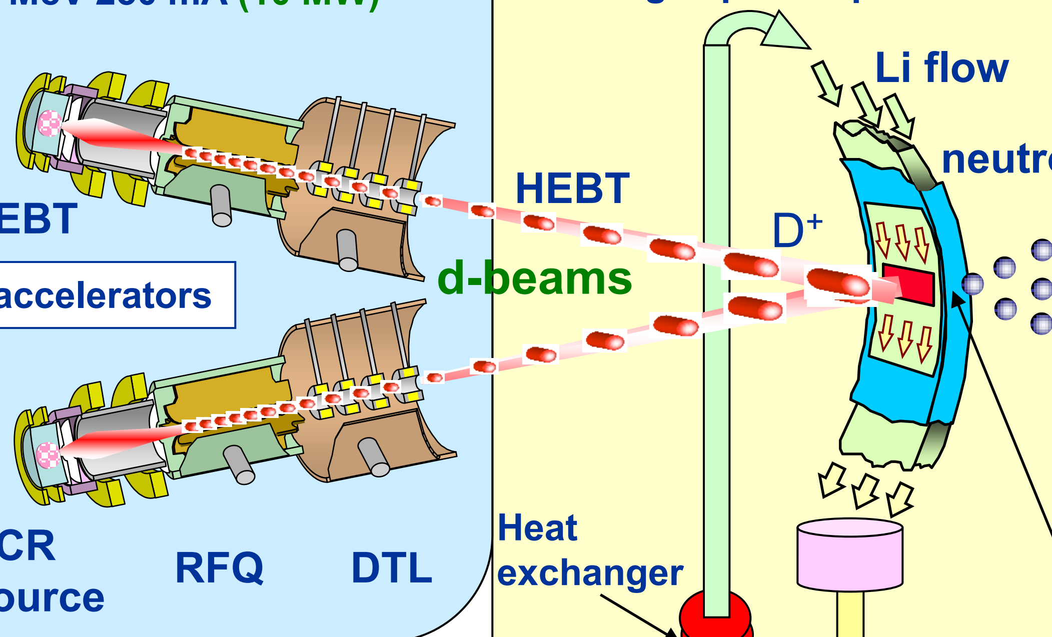
RFQ assembled

RF power system under completion

The Three Main IFMIF Components

Accelerator

Deuteron accelerators:
40 MeV 250 mA (10 MW)

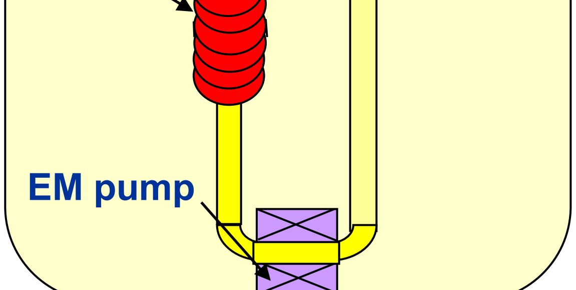


ECR source: 155 mA, 95 keV

Two 175 MHz Accelerators:
each 125 mA and 40 MeV, acceleration by Radio Frequency Quadrupoles (RFQ) and Drift Tube Linacs (DTL)

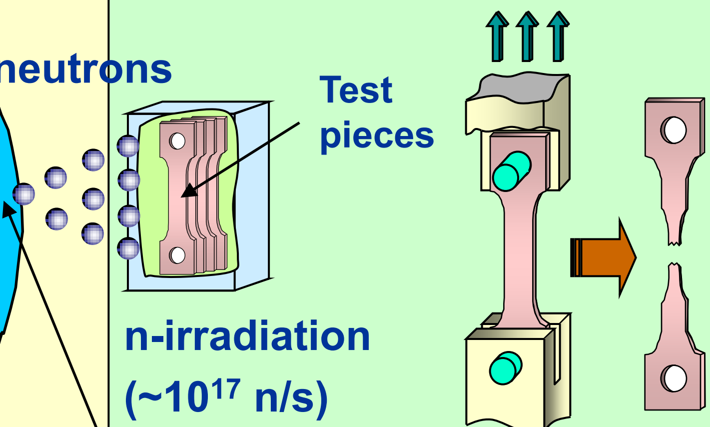
Target

- 10 MW beam heat removal with high speed liquid Li flow



Test Cell

- Irrad. Volume ~ 0.5L for 10^{14} n/(s·cm²), (≥20 dpa/year)
- Temperature: 250<T<1000℃



Typical reactions:
$^{7}Li(d,2n)^{7}Be$, $^{6}Li(d,n)^{7}Be$, $^{6}Li(n,T)^{4}He$

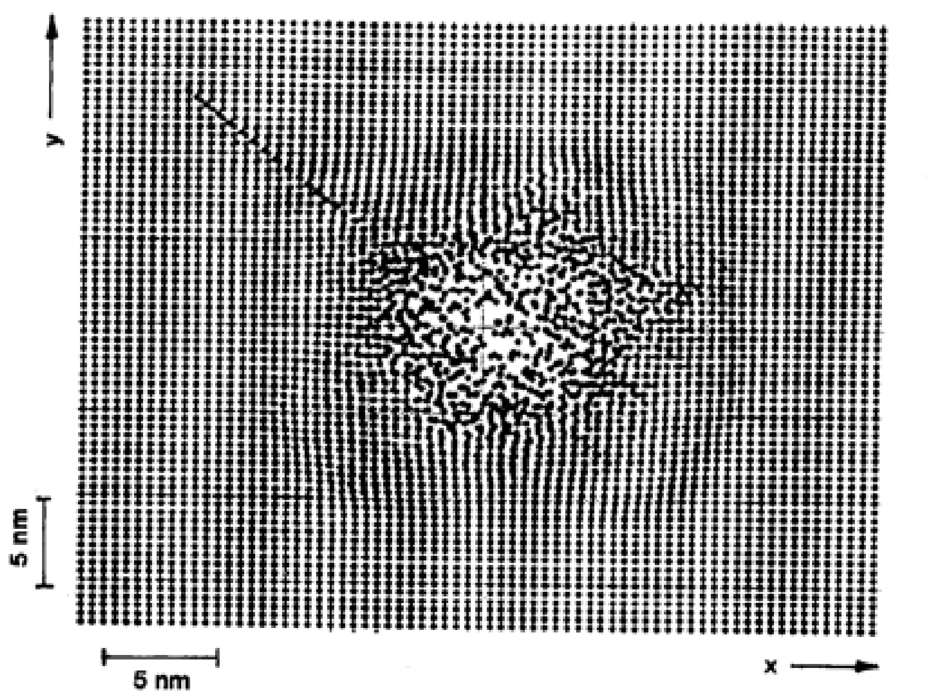
Footprint on target:
20cm wide x 5cm high (1 GW/m²)

Total Availability: 70%

Why IFMIF ?

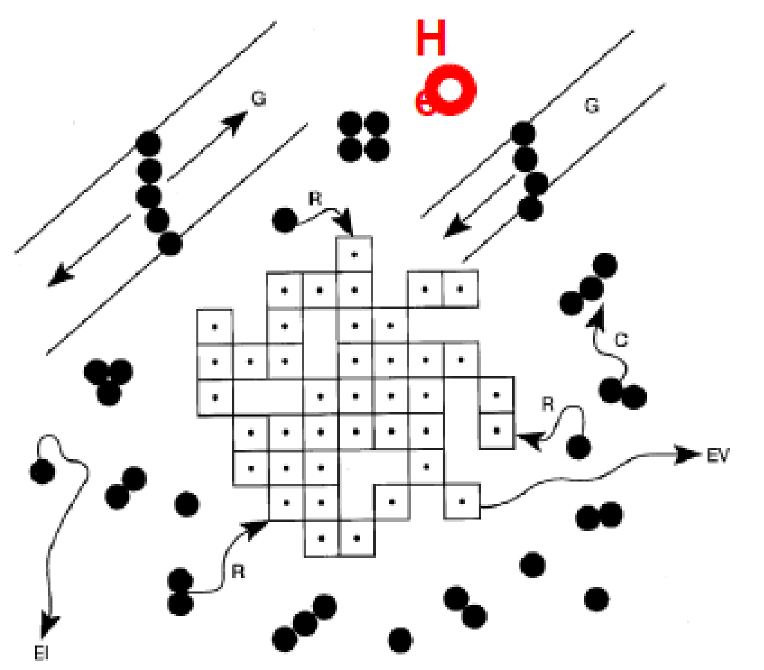
Irradiation damage: 2 elementary reactions

Atomic displacements („dpa“)



MD simulation of a displacement cascade produced by a 10 keV primary knock-on atom in an fcc lattice (Ghaly and Averback)

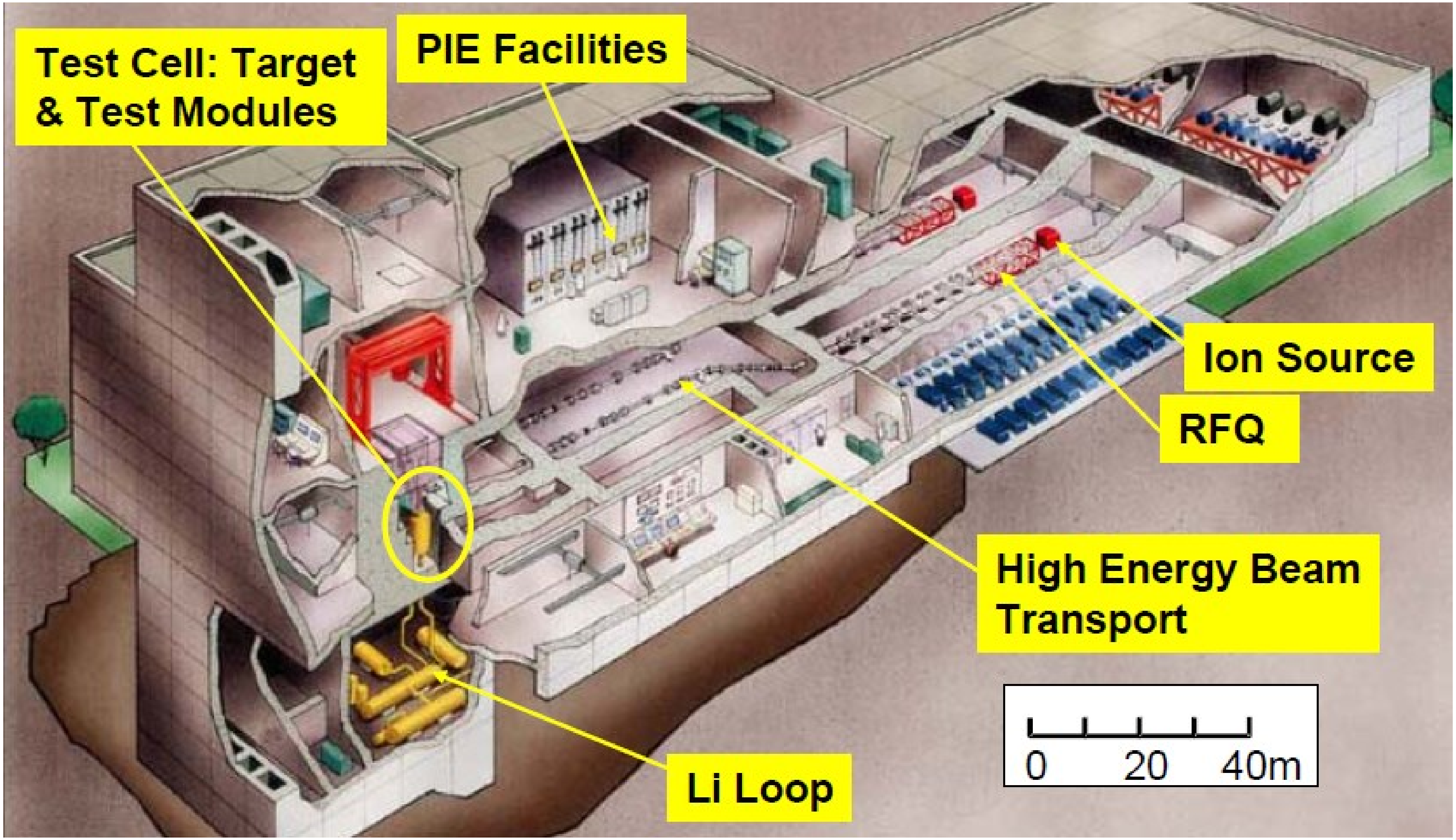
Nuclear reactions (e.g. He)



Defect arrangement in a displacement cascade (schematic)

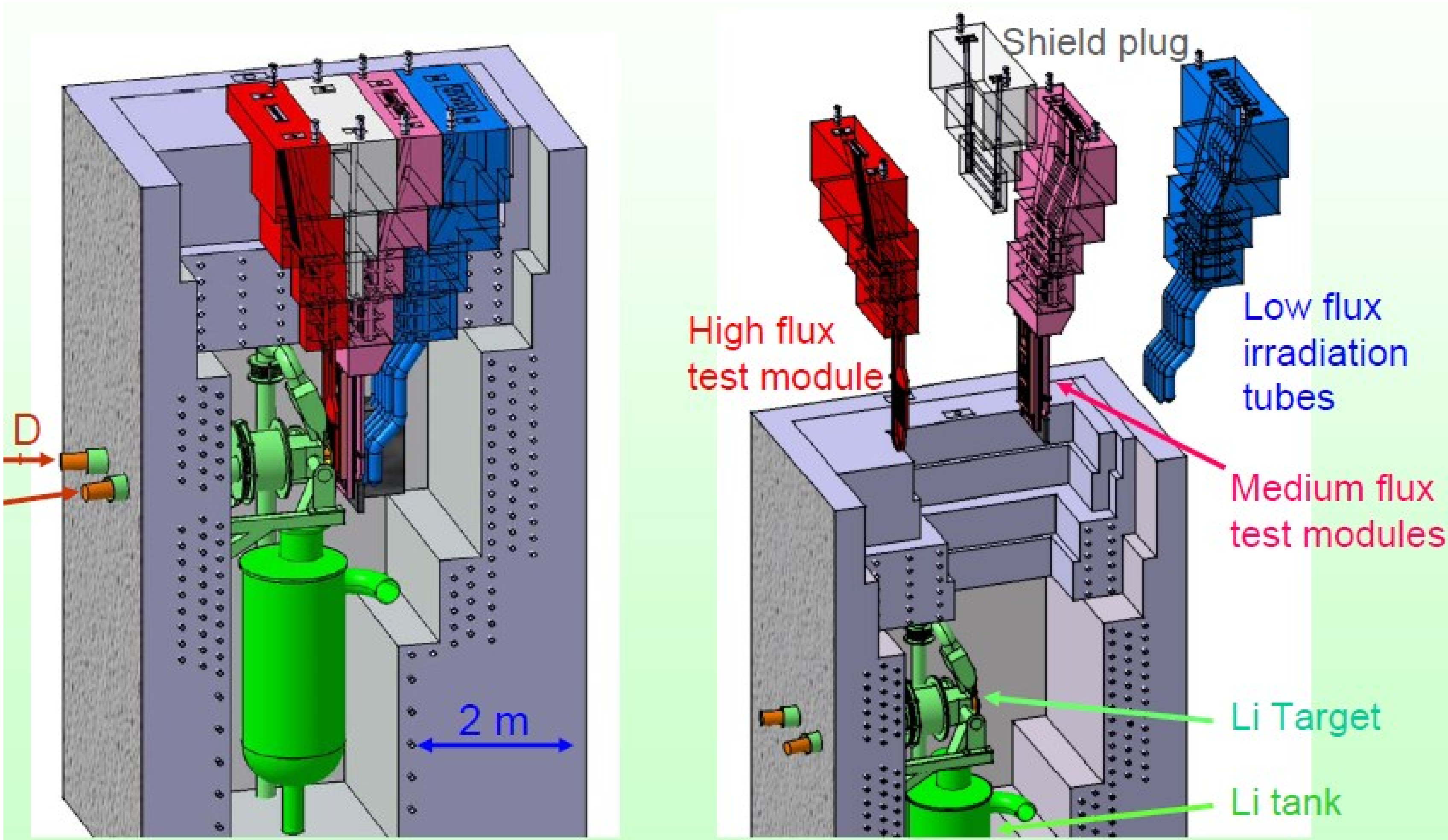
He effects: no adequate simulation in existing irradiation facilities

IFMIF



Total cost ~2 billion Euros, delays → EU “IFMIF – **DONES**”

IFMIF Test Cell



IFMIF/EVEDA Lithium Test Loop (ELiTe)

ELiTe Facility Building
[40m^{W}, 80m^{L}, 33m^{H}]
JAEA Oarai

- All components and piping are installed
- Interim inspection by the fire department successfully passed in August 2010
- Electrical instruments such as heaters, leak detectors and cables are now being installed

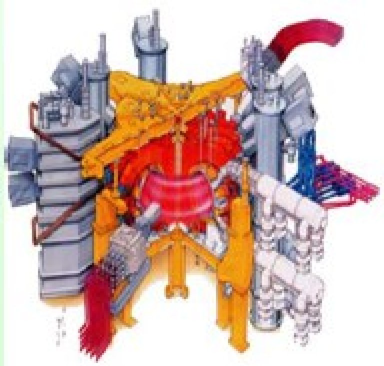
The ELiTe Loop under construction on 8 Sept. 2010

4. Beyond ITER: towards a Fusion Power Plant (FPP)

Towards fusion power plant

JT-60
JET

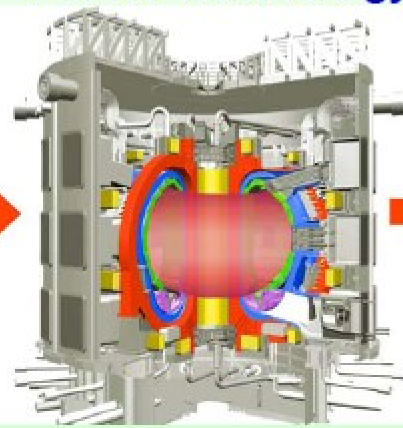
Break-even



Q~0.5-1 ~10sec

Experimental Reactor (ITER)

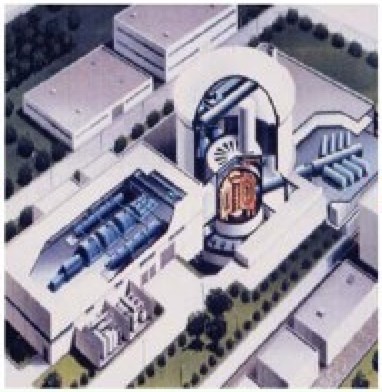
Long-burn
Integration of
Fusion Technology



Q ≥10 300~500sec

Demonstration Reactor (DEMO)

Electric Power
Generation
~1000 MWe



Q =30~50

Public Use

Irradiat. Damage:	≤3dpa / lifetime	≤30pda / year

Chinese Fusion Engineering Test Reactor (CFETR)

CFETR Conceptual Design (2013.11-2015.8)

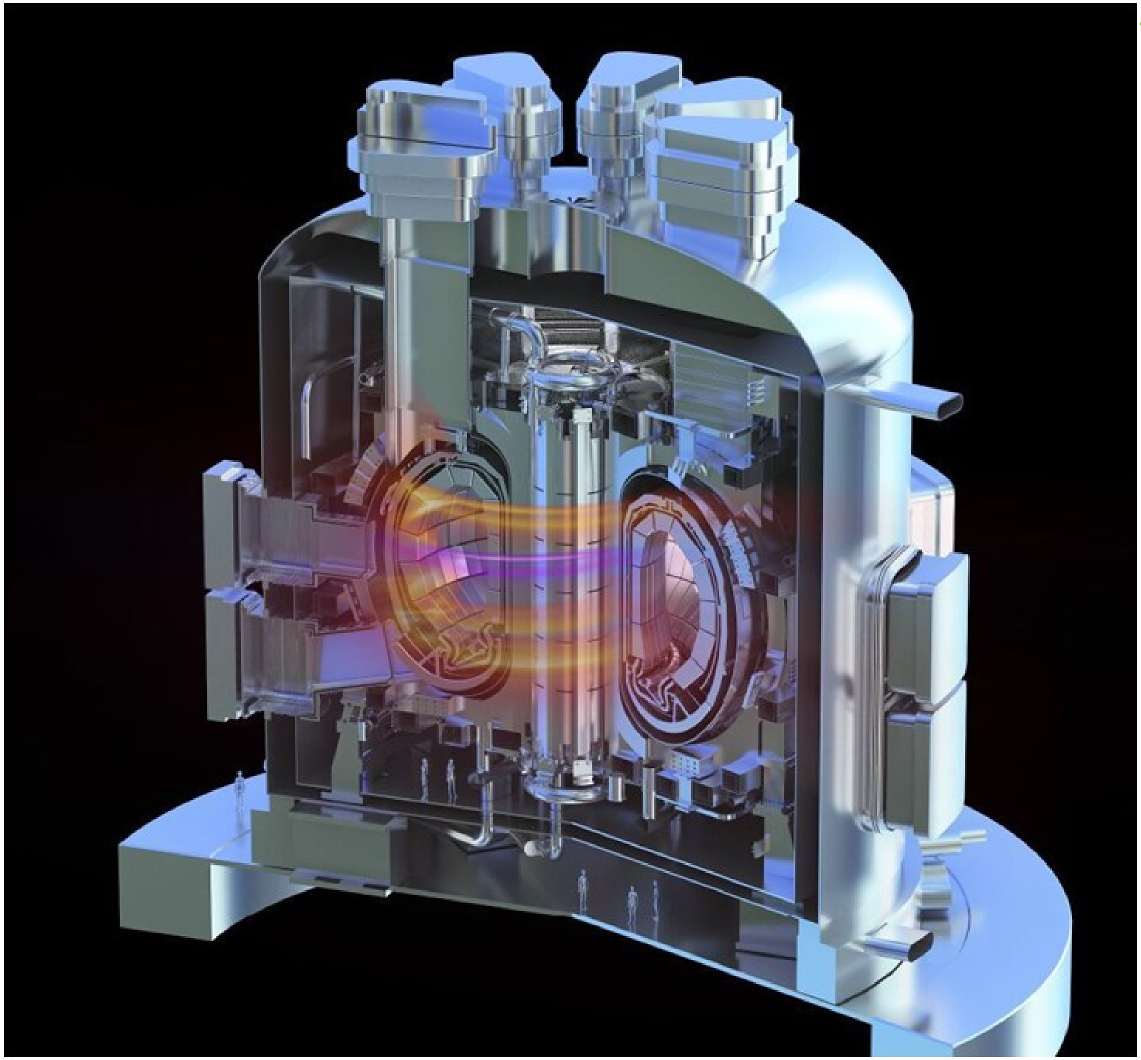
- I_p=7-10 MA
- B_{to} = 4.5-5.0T
- R_0 = 5.7 m ;
- a = 1.6 m;
- k=1.8 ~ 2.0
- $q_{95} \geq 3$;
- β_N ~ 2-3

P_{fusion}: 200MW

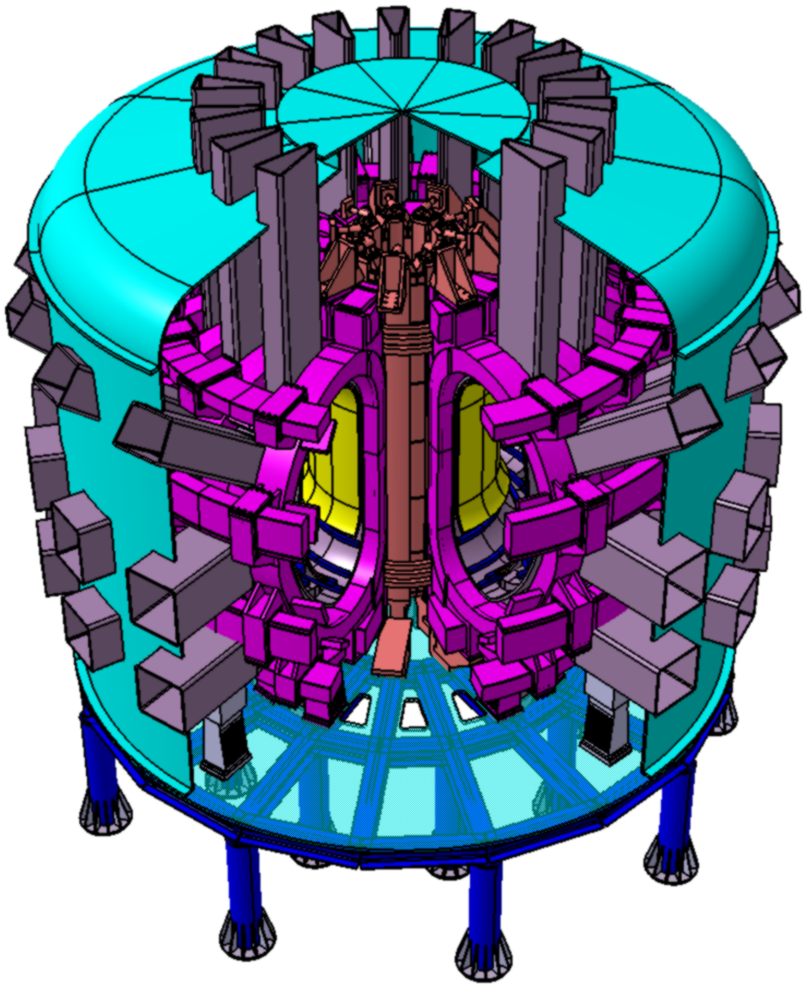
Possible upgrade to

R~6.0 m, a~2 m,

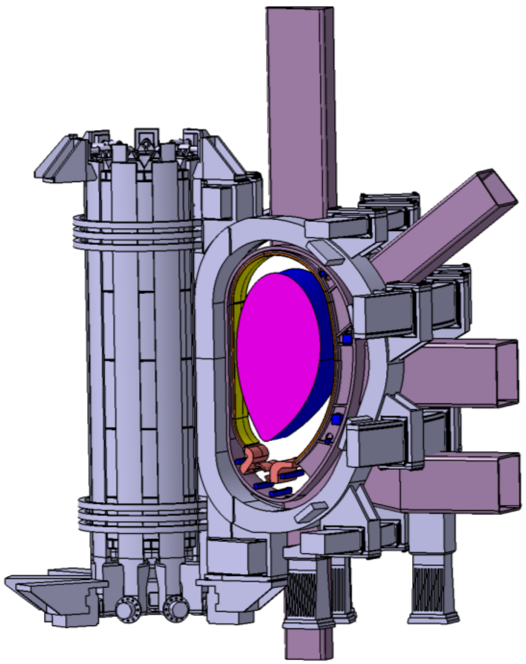
B_t= 7T, I_p~15 MA



Divertor Test Tokamak (Italy)



Sectional view of the DTT basic machine



Isometric view of one of the 18 DTT sectors with schematic representation of magnets and principal in-vessel components

DTT: Choice of main machine parameters

MAIN DTT PARAMETERS FOR THE REFERENCE SINGLE NULL SCENARIO

R (m)	**2.15**	β_N	1.5
a (m)	**0.7**	τ_{Res} (sec)	8
I_P (MA)	**6**	V_{Loop} (V)	0.17
B_T (T)	**6**	Z_{eff}	1.7
V (m^3)	33.0	P_{Rad} (MW)	13
P_{ADD} (MW)	**45**	P_{Sep} (MW)	32
H_{98}	1	T_{Ped} (KeV)	3.1
$<n_e>$ (10^{20} m^{-3})	1.7	n_{Ped} (10^{20} m^{-3})	1.4
n_e/n_{eG}	0.45	β_p	0.5
$<T_e>$ (KeV)	6.2	P_{Div} (MW/m^2) (No Rad)	~ 55
τ (sec)	0.47	**P_{Sep}/R (MW/m)**	**15**
$n_e(0)$ (10^{20} m^{-3})	2.2	P_{Tot}B/R (MW T/m)	125
$T_e(0)$ (KeV)	10.2	**λ_q (mm)**	**~ 2**

Comparison with ITER and DEMO

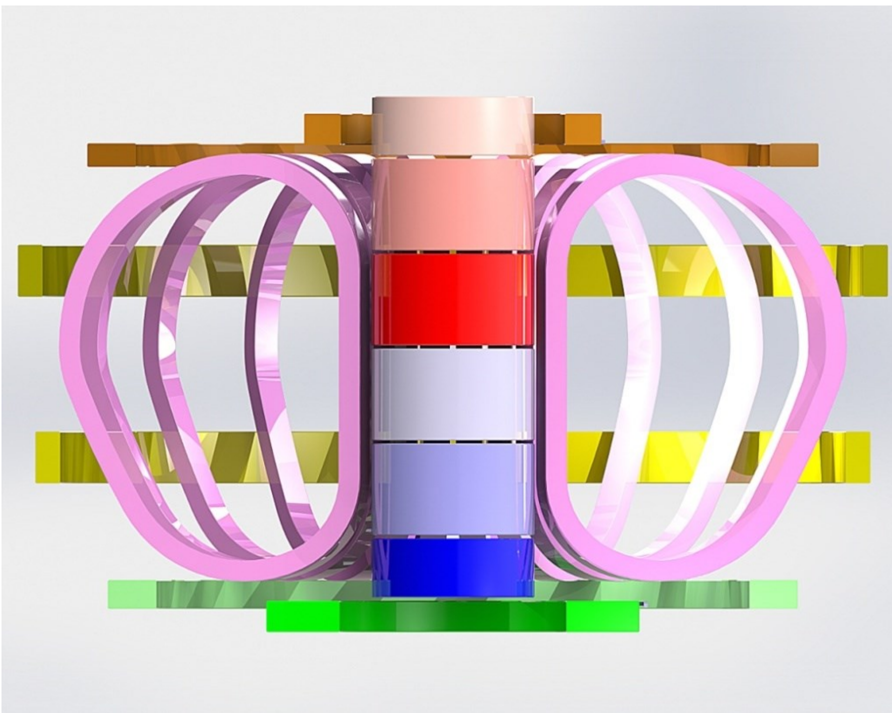
	DTT	ITER	DEMO
R (m)	2.15	6.2	8.77
a (m)	0.70	2.0	2.83
I_p (MA)	6.0	15	20
B_T (T)	6.0	5.3	5.8
V_p (m^3)	32	853	2218
<n> (m^{-3})	1.72	1.0	0.9
P_{Tot} (MW)	45	120	450
Cost (M€)	355	6500	??
t_E (s)	0.47	3.6	3.4
<T> (KeV)	6.2	8.5	12.6
b %	2.2	2.2	2.6
n^* (10^{-2})	2.4	2.3	1.3
r^* (10^{-3})	2.6	1	1.1

	DTT	ITER	DEMO
T_{Ped} (keV)	3.1	4.3	7.0
n_{Ped} (10^{20} m^{-3})	1.4	0.8	0.7
n^*_{Ped} (10^{-2})	6.3	6.2	2.8
ELM Energy (MJ)	1.2	24	140
L-H Power (MW)	16÷22	60÷100	120÷200
P_{Sep} (MW)	32	87	150
P_{sep}/R (MW/m)	15	14	17
l^1_m (mm)	1.7	2.2	2.2
P^2_{Div} (MW/m^2)	54	55	84
P^3_{Div} (MW/m^2)	27	27	42
$q_{//}\approx P_{Tot}B/R$ (MWT/m)	125	100	290
Pulse Time (s)	≈ 100	400	7000

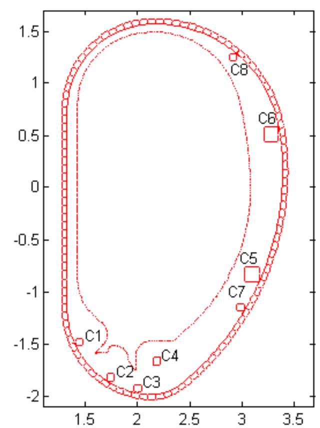
DTT: magnets

Magnet system: CS, PF coils and TF Coils

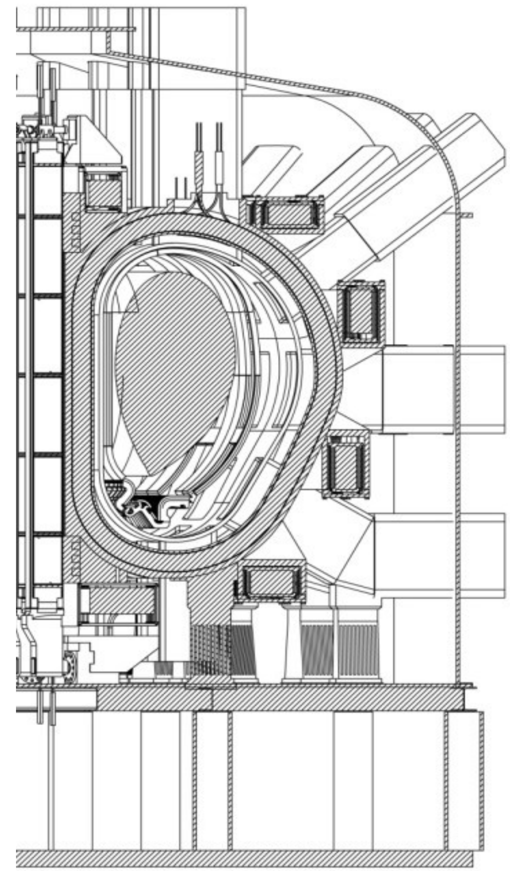
18 TF coils: B_{peak}: 11.4 T, B_{plasma}: 6.0 T, 65 MAt;
6 CS coils: B_{peak}: 12.5 T, $\Sigma_k |N_k I_k|$ =51 MAt; available poloidal flux: ±17.6 Vs;
6 PF coils: B_{peak}: 4.0 T, $\Sigma_k |N_k I_k|$ =21 MAt.



CS, PF coils and TF Coils

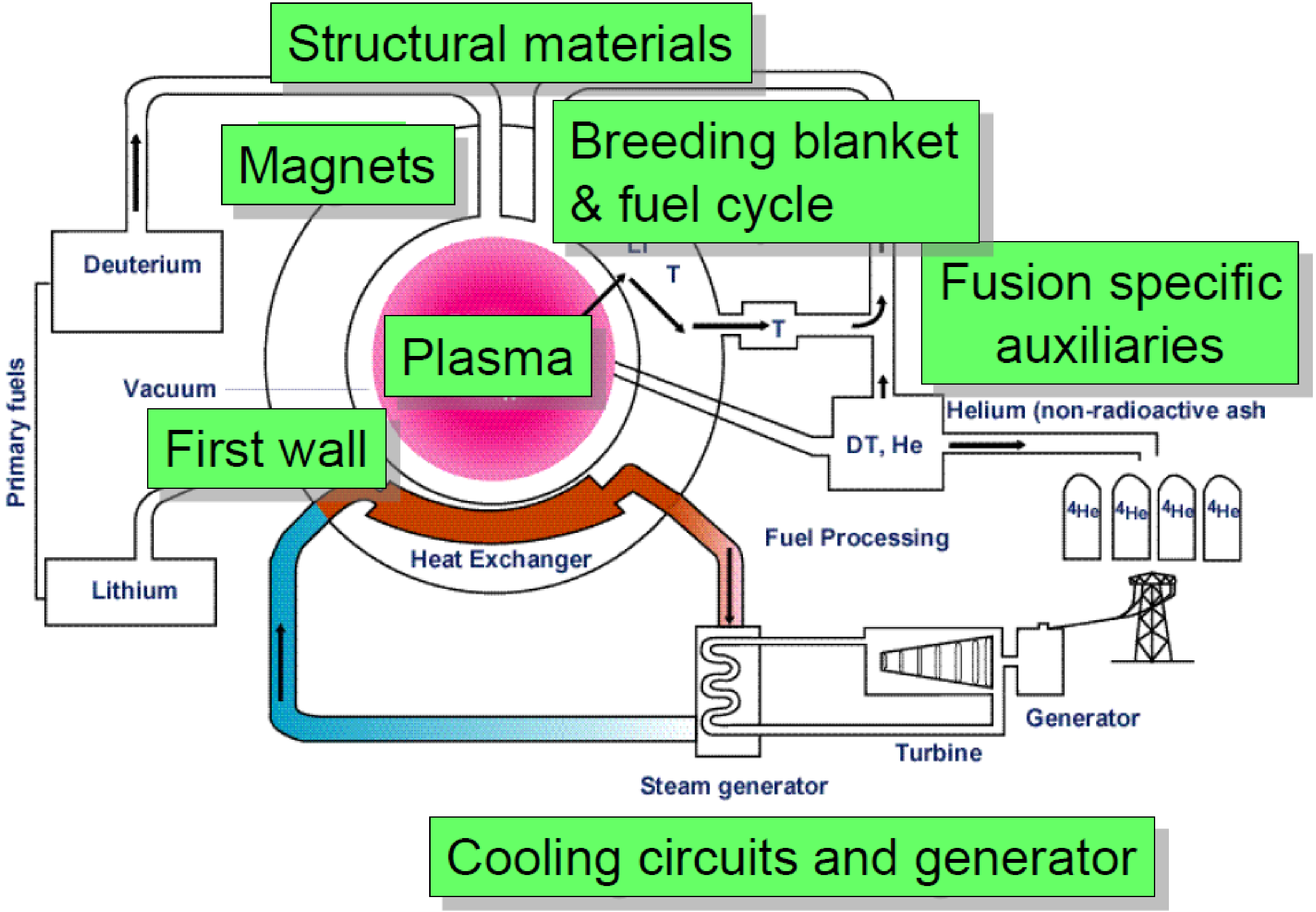


in-vessel coils



DTT

DEMO


Structural materials
Magnets
Breeding blanket & fuel cycle
Fusion specific auxiliaries
Plasma
First wall
Cooling circuits and generator
Deuterium
Lithium
Primary fuels
Vacuum
T
T
Helium (non-radioactive ash
DT, He
Fuel Processing
Heat Exchanger
Steam generator
Turbine
Generator

DEMO engineering challenges

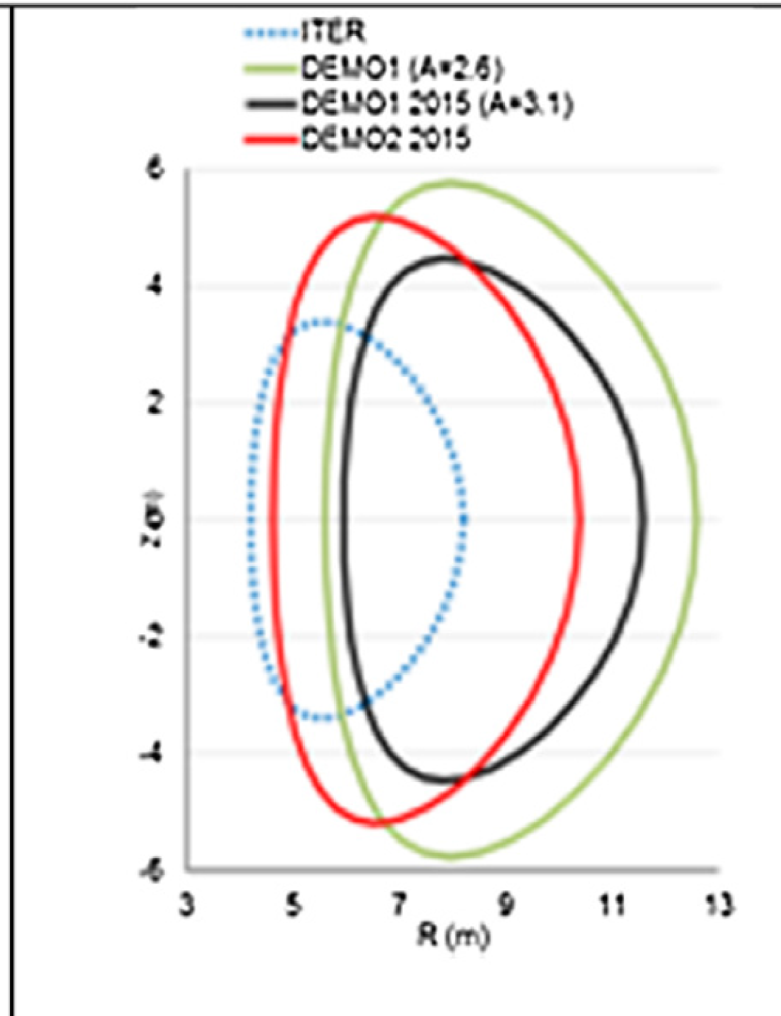
Many solutions can be adopted from ITER – these will not be treated here

The EU programme has identified the following DEMO technology challenges, i.e. items that will qualitatively go beyond ITER

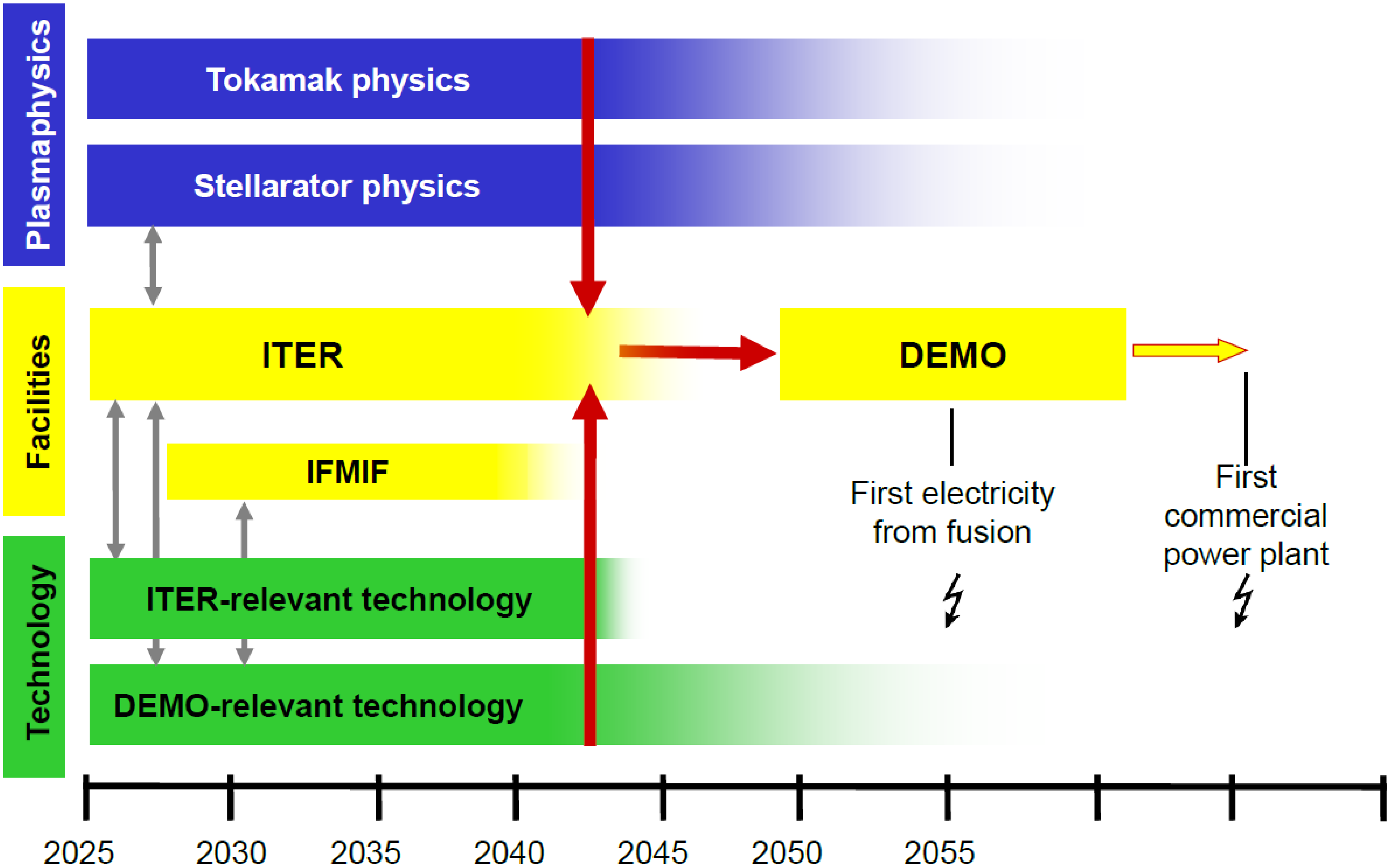
- Enabling technologies (H&CD, Diagnostics and control, T processing etc.) have to have highest **availability, reliability** and **efficiency**
- **Materials** have to cope with much higher n-fluences at adequate lifetime and, at the same time, low radiological burden
- **T-self sufficiency** has to be guaranteed

‚DEMO is no longer an experiment' – industry should be involved early on!

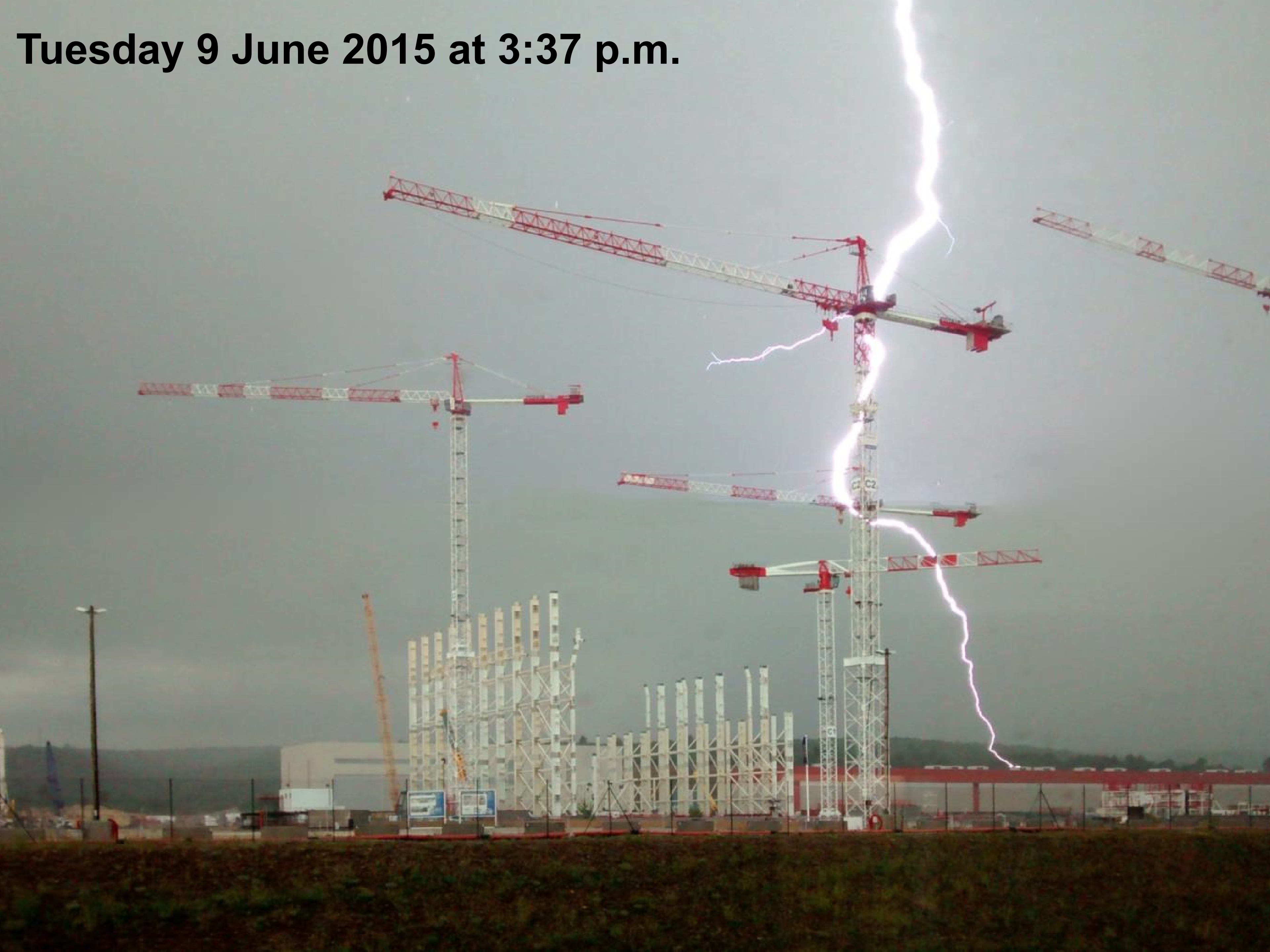
	ITER Q=10	DEMO1 A=2.6	DEMO1 A=3.1	DEMO2
R [m]	6.2	9.5	9.1	7.5
S [m^2]	683	1895	1428	1253
V [m^3]	831	4174	2502	2217
P_{fus} [MW]	500	2074	2037	3255
$_{burn}$ [h]	0.1	2	2	inf
I_P [MA]	15	24	20	22
B_T [T]	5.3	3.8	5.7	5.6
$\beta_{N,tot}$ [%]	1.8	2.9	2.6	3.8
T_{e0} [keV]	11.5	26.8	27.4	34.7
n_{e0} [10^{19} m^{-3}]	12.5	8.2	10.1	12.2
$P_{rad,core}$ [MW]	47	318	331	694
P_{CD} [MW]	70	50	50	133
q_{NW} [MW/m^2]	0.5	0.8	1.1	1.9



G. Federici et al., Overview of the design approach and prioritization of R&D activities towards an EU DEMO FED 109-111 (2016) 1464


Plasmaphysics
Tokamak physics
Stellarator physics
Facilities
ITER
DEMO
IFMIF
Technology
ITER-relevant technology
DEMO-relevant technology
First electricity from fusion
First commercial power plant
2025
2030
2035
2040
2045
2050
2055

No conclusions yet…


Tuesday 9 June 2015 at 3:37 p.m.